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Issued September 30, 1910.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS—BULLETIN NO. 70.
MILTON WHITNEY, Chief.

SOME EFFECTS OF A HARMFUL ORGANIC SOIL CONSTITUENT.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., January 7, 1910.

Sir: I have the honor to transmit the manuscript of a scientific paper entitled Some Effects of a Harmful Organic Soil Constituent, by Dr. Oswald Schreiner, in charge of Fertility Investigations, and J. J. Skinner, of this Bureau. I recommend that this paper be published as Bulletin No. 70 of the Bureau of Soils.

Respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

The researches into the nature and properties of soil organic matter, of which this bulletin is a part, have shown conclusively that the soil investigator must take into consideration the presence of organic compounds in the soil, which may be beneficial, inert, or inimical to growing crops. The presence of the harmful compounds may cause, according to their specific action or to the amount in which they are present, all stages of crop depression, from effects probably in many cases so slight as not to be noticed in actual difference in yield, though perhaps in quality or keeping quality of special crops, to the more marked effects when practical sterility is observed. A complete solution of the difficulty, which the presence of such bodies may occasion the practical tiller of the soil, can only be reached by a thorough inquiry into the chemical and biological nature of such compounds; by a knowledge of their origin and the causes leading to their formation or accumulation in the soil; and by an investigation into treatments of the soil—chemical, such as the addition of fertilizers, lime, etc., or physical, such as drainage, cultural methods, etc., or biological, such as the influence of crops and their remains on the soil, crop succession or crop rotation, number and kind of bacteria, fungi, etc.—in order that the best practical means for their removal, destruction or prevention may be determined and soil treatments be more scientific in the future than they have been in the past, with consequent greater and surer returns for the money and labor expended.

The chemical, physical, and biologic treatments, or factors, can not well be studied or altered independently. A chemical treatment such as the application of fertilizers or lime produces at the same time a physical effect on the soil, such as flocculation, deflocculation, etc., and a biological effect in changing the bacterial or other micro-organic flora, especially if the treatment is continued for many years. Conversely, any attempt to change the physical condition of the soil, or the biological conditions, whether by micro-organisms or higher plants, produces a concomitant chemical change in the soil, especially, although by no means exclusively, in the organic matter, so that this becomes altered, resulting in beneficial or harmful changes, as the case may be.

A former investigation dealt with the isolation and identification of some of these organic soil compounds. In the present investigation

an attempt is made to study the effect of chemical soil treatments, such as the application of fertilizers on one of these organic soil compounds. A great many different ratios of fertilizer elements were used, so as to obtain a comprehensive view over the entire range of fertilizer treatment, from the single carriers of nitrogen, phosphorus, and potassium, to numerous combinations of any two or three of them.

This investigation involved two distinct methods of study, the synthetic and the analytic. The synthetic consisted in preparing the pure chemical soil constituent and dissolving it together with the various combinations of fertilizer salts in known ratios and amounts in pure distilled water and noting the effect as shown by the plant. The analytic consisted in noting the development and growth of the plant and analyzing the solution in which it was growing in order to learn what was going on in the course of the experiment. Neither of these results alone, however, could have been properly interpreted, and it was by the combination of the two that much valuable information concerning the phenomena which took place in these experiments could be obtained.

Inasmuch as there was necessary a considerable amount of detail work which required immediate attention periodically, the investigation was made possible only through the earnest cooperation of several men in this laboratory. Especially valuable assistance was rendered by Dr. E. C. Shorey in making the nitrate determinations, by Mr. F. R. Reid in making the phosphate determinations, and by Mr. A. M. Jackson and Mr. J. H. Beattie in the cultural work.

Oswald Schreiner,
In Charge Fertility Investigations.

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SOME EFFECTS OF A HARMFUL ORGANIC SOIL CONSTITUENT.

INTRODUCTION.

The investigation of infertile soils from various parts of the United States has received considerable attention in the last few years and has been conducted along several converging lines in these laboratories. The earlier researches of the bureau proved that in many of the soils studied there is no correlation possible between their mineral composition and their crop-producing power, either as shown in the field or as shown in the laboratory by the use of soil tests or solution culture tests prepared by making an aqueous extract of the soil and growing plants therein as an indicator of whether the soil solution itself was favorable or unfavorable to plant growth. Such experiments showed, indeed, that the crop-producing power of the soil is transmitted to its extract and that the extract prepared from such unproductive or infertile soil is less suitable for plant development than one prepared from a good soil. This difference in some cases was so striking that the plant development in the extract of a soil, which nevertheless contained mineral plant nutrients, was less than in pure distilled water free from any nutrient material whatever. Such a result indicates, therefore, that in soils which show this distinctive difference, there are present bodies which interfere with the normal development of plants. Further studies show that the harmful influence of the extract from such soils can be removed therefrom by certain treatments, such as boiling, distilling, or removal by means of absorbing agents like carbon black, ferric hydrate, or other finely divided bodies having an absorptive power. The harmful influence of the poor soil extract can also be removed by evaporating to dryness and igniting the residue, or it can be overcome by processes which promote oxidation. It can either be removed or its harmful effects overcome to a considerable extent by the introduction of nutrient salts or manure extract. The general properties exhibited by these extracts not only point to the presence of a body harmful to plant development, but indicate also that the compound is organic rather than mineral.

The quantity of material contained in the water extract employed was too small for study by chemical methods in the absence of specific knowledge concerning physical and chemical properties of the sub-

stance. A thorough inquiry into the nature of the organic matter of soils was, therefore, made with a view to isolating and studying such products. The results of these researches into the chemistry of the organic matter of the soil, its origin, transformation, and properties, have been reported upon to a large extent in a former bulletin of this bureau.[a] These researches have led to the discovery in such infertile soils of organic compounds that are harmful to plant growth. Several bodies have been isolated from such soils, which have quite different chemical properties, thus showing that there is a difference in the nature of the chemical compounds in different soils. Some of the bodies isolated contained nitrogen, while others were free from this element and contained carbon, hydrogen, and oxygen only. The presence of sulphur and phosphorus compounds has also been strongly indicated by these studies, although the actual identification of bodies of such nature has not been definitely accomplished. The results are sufficient, however, to show that compounds having a wide range of composition exist in the soils and a more detailed knowledge of their nature and properties seems imperative in order to know and understand the nature of the material influencing crops in the field and the action of fertilizers upon these, either directly or indirectly, through the medium of root oxidation and reduction or by microbiologic and enzymotic influences.

In this bulletin are reported experiments on the effect of a harmful soil constituent upon plant growth and upon the soil solution and fertilizer action, especially in reference to the ratio of phosphate, nitrate, and potash originally present and removed in the course of the experiment.

INFLUENCE OF HARMFUL ORGANIC SOIL CONSTITUENTS.

In an earlier paper [b] it was demonstrated that the roots of plants possessed a very appreciable oxidizing power, and this oxidation was enzymotic in character. This oxidizing power of the normal root was found to be influenced by the medium in which it grew. Thus good soils and their aqueous extracts promoted oxidation, while the poorer soils hindered this function of the roots. Some substances harmful to plant growth were also found to have an inhibitive effect on this oxidation. When smaller amounts were present, however, it was found that the oxidizing power of the roots was able to overcome the harmful influence. An examination in one case, namely, that of vanillin, where it was possible to demonstrate by colorimetric test the presence or absence of minute amounts, showed that this disappeared entirely from solution under the influence of the oxi-

[a] Bul. 53, Bureau of Soils, U. S. Dept. Agr.

[b] Schreiner and Reed, Bot. Gaz., **47**, 355, May, 1909; also Bul. 56, Bureau of Soils, U. S. Dept. Agr.

dizing power of the roots. It was further shown that the fertilizer salts, in addition to promoting plant growth, also had a very strong influence in promoting this enzymotic action, this being especially marked in the case of sodium nitrate and of lime. The action of fertilizer salts and the influence of such harmful soil constituents were, therefore, further investigated and the results given in connection with the other factors reported in this paper. All of the harmful bodies which had been studied and presented in previous papers had a distinct influence on the roots, causing them in many cases to become stunted or swollen and darkened at the tips, or to show other physiological irregularities of the same kind as is exhibited by the roots in different extracts from infertile soils. It is, therefore, of interest to know further the influence which such altered root conditions would have upon the composition of the soil solution and the influence of added fertilizers.

One of the bodies isolated from a considerable number of unproductive soils is a definite crystalline body identified as dihydroxystearic acid. The frequent occurrence of this body in such soils and its disappearance therefrom by processes which promote aeration or oxidation made this especially suitable for further study of its effects on plant development in relation to the concentrations of soil solutions or fertilizer application. As already mentioned, dihydroxystearic acid is a white crystalline body. The one isolated from soils melts at 98° to 99°, thus showing that it is the dihydroxystearic acid which had previously been prepared only in the laboratory from elaidic acid. There are several dihydroxystearic acids known, one being derived by the oxidation of oleic acid and iso-oleic acid and a natural product found in several oils.

The dihydroxystearic acid can be isolated from a soil containing it by treatment with a 2 per cent sodium-hydroxide solution, and after allowing the mineral material to settle the alkaline extract is separated and made acid with a slight excess of acetic acid. The so-called humus precipitate which is thus formed is filtered off and the clear filtrate is shaken out with ether and the ether solution allowed to evaporate on the surface of a small quantity of water. The dihydroxystearic acid is left on the surface of the water, together with other impurities extracted by the ether. These impurities can be largely removed by heating the water to boiling, and filtering. The dihydroxystearic acid is dissolved in the hot water, and on cooling crystallizes out in the form of small plates or leaflets arranged in radiating clusters. The details of the method of isolating and purifying will be found in Bulletin No. 53 of this bureau.

Dihydroxystearic acid can also be prepared in the laboratory, and this was done in these experiments, by starting with oleic acid, which by treatment with nitrous oxide is changed to the isomeric elaidic

acid. The elaidic acid thus formed is dissolved in a solution of potassium hydroxide and oxidized by a solution of potassium permanganate, one of the products under suitable conditions being dihydroxystearic acid. Care has to be taken that the oxidation does not proceed too far, for the dihydroxystearic acid is very readily oxidized to other compounds.

In these investigations culture solutions containing the three fertilizer ingredients, namely, P_2O_5, NH_3, and K_2O, as calcium acid phosphate, sodium nitrate, and potassium sulphate, respectively, in all possible ratios of one, two, and three constituents, varying the individual ingredients in stages of 10 per cent, were prepared, the concentration being 80 parts per million. In a similar set of cultures there were added 50 parts per million of dihydroxystearic acid to each culture. The selection of the salts as carriers of the phosphate, nitrate, and potash and the terms of P_2O_5, NH_3, and K_2O is in harmony with the practice in fertilizer work. The salts selected, it will be seen, are also carriers of calcium, of sodium, and of sulphate, and the three salts, therefore, were practically the best that could be selected for giving at the same time other needed constituents.

The concentration of the culture solution of these three salts was in each case a total of 80 parts per million of P_2O_5, NH_3, and K_2O, but varied, as above noted, in the ratio in which they were present. The concentration of the harmful soil constituent—in this case dihydroxystearic acid, which has been found in very appreciable amounts in a number of unfertile soils—was 50 parts per million. Wheat plants were then grown in these various cultures with and without dihydroxystearic acid and observations were made in regard to general development, the effect on root growth and appearance, and on root oxidation, and at the termination of the experiment the green weight of the plant was taken. The solutions were changed every three days and an analysis was made, the phosphate, nitrate, and potash being determined, thus giving the concentration of these elements and their ratios existing at the end of every three-day period for comparison with the original concentration and ratio. This changing of the solutions was kept up for twenty-four days, thus making eight changes. In this work the methods devised in the bureau for the determination of small amounts of such constituents rendered excellent service and point the way for their further use upon other problems in connection with the biochemical relationships of soils and plants, which have hitherto been almost impossible of attack. In the discussion and presentation of the results the triangular diagram as used in physical chemistry was employed and has proven very useful as a guide in the work for the systematic handling of the experimental details. The results can best be presented or interpreted by its means.

The general effect of the dihydroxystearic acid was very marked in all of the cultures, reducing the growth approximately 40 per cent. It was so harmful even in the dilute concentration of 50 parts per million used in these experiments as to be completely overcome in but few of the cultures. This reduction in growth was in general the less marked when all three fertilizing constituents were present. The least effect of dihydroxystearic acid was associated with those cultures in which the greatest growth occurred under normal conditions; i. e., the dihydroxystearic acid had the least effect in those cultures where the ratios were the best suited for the promotion of plant growth. In addition to the effect on growth as determined by general appearances and green weight, the roots were also greatly affected and their ability to oxidize was completely destroyed, except in those ratios best suited for plant development. The roots were usually discolored, with blackened and swollen tips, which were often turned upward in the form of hooks. This effect was the most marked in the cultures containing only one or two of the above salts and was the least marked where the three were present. The least effect on the roots was found in the region where the ratios were the best for plant development under normal conditions.

Associated with this effect on plant growth and root condition was the different removal of mineral constituents from the nutrient solutions. In general, the removal of phosphate, and especially of potash, was greatly diminished. The decrease in nitrate was on the whole about the same in the solution with and without the dihydroxystearic acid; if anything, it was somewhat greater in the latter case. The total removal of the three constituents was less than where the dihydroxystearic acid is absent. The fact also that the nitrate concentration in the cultures was not markedly different from that under normal conditions, whereas the phosphate and potash concentrations were greater, had the effect of increasing the ratio of the nitrogen in the material removed from the solution.

When the relative effect of the dihydroxystearic acid on the different ratios is considered, it is found that in general the effect is less marked in the case of those mixtures which are mainly nitrogenous; this is indicated by the relatively greater green weight observed in these ratios as a whole and also by the more normal removal of the three constituents.

In addition to the effect of the dihydroxystearic acid in these various cultures, the growth relationships and concentration differences observed between the different ratios of mineral constituents in which the plants were grown, varying from single constituents to mixtures of two and three in all possible ratios in 10 per cent stages, are of the greatest interest and value, inasmuch as such a compre-

hensive study of the effect of ratios of these constituents has never been made. Especially is this true of the analyses of solutions in which plants have grown.

The greatest growth always occurred where the three fertilizing elements were present and is usually found in those mixtures which contained between 10 and 30 per cent phosphate, between 30 and 60 per cent nitrate, and between 30 and 60 per cent potash. The growth in these ratios was always greater than the growth in other ratios of the three constituents and was very markedly greater than with any mixtures of two constituents or with single fertilizer elements. In the presence of the dihydroxystearic acid, as already pointed out, there was a tendency for the region of greater growth to be found where the proportions of nitrogen were somewhat high.

The concentration differences noticed in the solutions were also very striking, the greater reduction in concentration occurring where the greatest growth occurred.

The change in the ratios of the solutions and the ratios of the materials that were removed from them showed that in the region where the greatest growth occurred, as above outlined, the solutions suffered the least change in ratio, although the greatest change in concentration occurred in this region. The farther the ratios in these solutions were removed from the ratios found in the region of the greatest growth, the more were the solutions altered in the course of the experiment, the tendency in all cases seeming to be to remove from any and all of these solutions the ratio which normally existed in this region. The effect of the dihydroxystearic acid, however, upon this ratio of the removed material was, as already pointed out, to shift this slightly toward a greater nitrogen removal.

The results also show that the higher the amount of any one constituent present in the solution the more does the culture growing in that solution take up of this constituent, although it does not seem to be able to use this additional amount economically.

USE OF THE TRIANGULAR DIAGRAM AS A GUIDE IN THE WORK.

The number of solution cultures required in order to have all the possible ratios as outlined in the previous section is 66. To bear in mind these 66 ratios for three different ingredients, together with the ratios of the solutions after the plants had grown and perhaps also the ratios of the material removed from the solution, a total of 594 numbers, is practically an impossibility, and it is readily seen that in order to discuss such a comprehensive experiment as this the material must be reduced to a workable basis so that the various phases of the results can be kept in mind and the proper correlation and comparisons made. The triangular diagram as suggested by

Schreinemacher[a] in 1893 and again by Bancroft[b] in 1902 has been of the greatest service to physical chemistry where both theoretical and practical consideration of percentage composition of three component parts are concerned.

In the present investigation we have likewise to consider the three component parts of the fertilizer mixture, namely, P_2O_5, NH_3, and K_2O. It is therefore possible to represent any mixture of these three component parts in the triangular diagram. Such a triangular diagram is shown in figure 1. It is an equilateral triangle in which the extreme points of the angles represent 100 per cent, respectively,

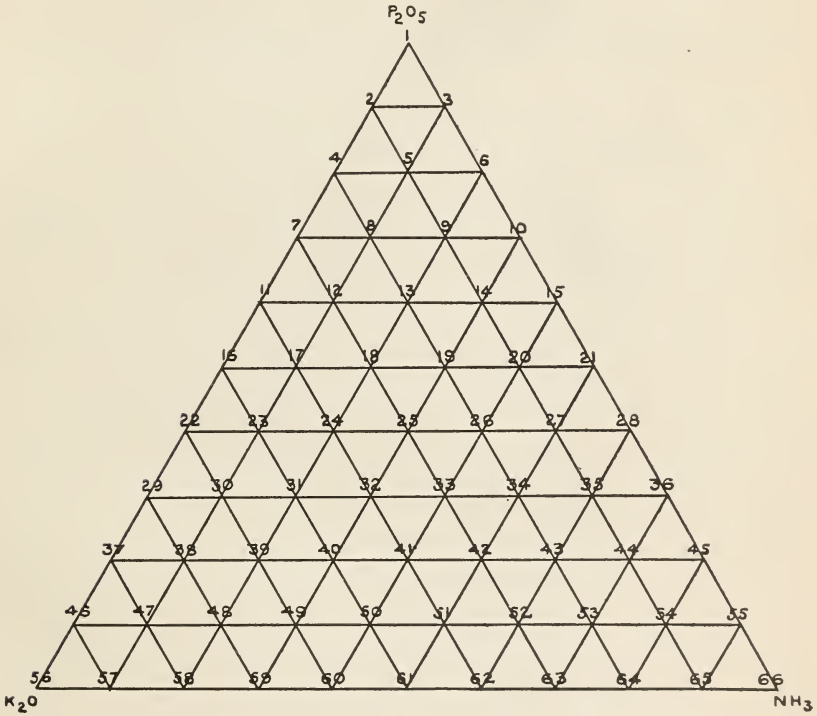

FIG. 1.—Triangular diagram, with the points representing the 66 culture solutions numbered.

of the ingredients, P_2O_5, NH_3, and K_2O, as shown in the diagram. Each side of the triangle is divided into ten equal parts and lines are drawn connecting these points.[c] In the diagram, for the sake of ready reference, the intersections of these lines have been numbered. If we consider the line representing the base of the triangle, it is obvious that the point which represents 100 per cent K_2O (56 in the

[a] Zeit. Phys. Chem., **11,** 81 (1893).

[b] Jour. Phys. Chem., **6,** 178 (1902).

[c] Such diagrams for physical chemical work, giving still finer rulings, namely, 100 to each line, can be purchased from the Cornell Cooperative Society and were used in these investigations.

diagram) represents at the same time 0 per cent NH_3, and the point 100 per cent NH_3 (66) likewise represents 0 per cent K_2O. If we take a point half way between these two points, for instance point 61, we have a mixture of the two salts in equal proportions; i. e., a mixture of the salts represented by that point will be 50 per cent K_2O and 50 per cent NH_3. Similarly point 16 represents 50 per cent K_2O and 50 per cent P_2O_5, and point 21 represents 50 per cent NH_3 and 50 per cent P_2O_5. If we take a point nearer to either of the corners, we will have a higher percentage of that ingredient and a correspondingly lower percentage of the other. For instance, at the point 59 the composition is 70 per cent K_2O and 30 per cent NH_3; at 29 it is likewise 70 per cent K_2O, but 30 per cent P_2O_5; at 64 it is 20 per cent K_2O and 80 per cent NH_3; at 45 it is likewise 80 per cent NH_3, but 20 per cent P_2O_5.

As stated above, points on the base line 56 to 66 represent mixtures containing no P_2O_5. The next line above this, namely, 46 to 55, represents mixtures containing throughout 10 per cent P_2O_5, but varying amounts of the other two constituents. Similarly the line 37 to 45 represents throughout 20 per cent mixtures of P_2O_5; line 29 to 36, 30 per cent mixtures of P_2O_5, and so on upward until point 1, the apex of the triangle, is reached, where the composition is 100 per cent P_2O_5, as already explained. Similarly points on the line 1 to 66 represent 0 per cent K_2O; line 2 to 65 represents 10 per cent K_2O, but varying amounts of P_2O_5 and NH_3, and so on until at point 56 the composition is 100 per cent K_2O. Likewise points on the line 1 to 56 represent 0 per cent NH_3; line 3 to 57 represents 10 per cent NH_3, but varying amounts of P_2O_5 and K_2O, and so on until at point 66 the composition is 100 per cent NH_3. It is therefore obvious that any point within the triangle represents a mixture composed of the three constituents, its position in the triangle being determined by the composition, namely, the percentage of the three component parts, P_2O_5, NH_3, and K_2O. For instance, point 12, being on the 60 per cent phosphate line, represents this composition of P_2O_5, namely, 60 per cent, and being at the same time on the 10 per cent NH_3 line and the 30 per cent K_2O line it represents 10 and 30 per cent of these constituents, respectively. The composition of the mixture represented by this point is therefore P_2O_5 60 per cent, NH_3 10 per cent, K_2O 30 per cent, i. e., the ratio of these constituents in the fertilizer mixture is 60–10–30 or 6–1–3. Similarly the point 34 represents a mixture of the composition P_2O_5 30 per cent, NH_3 50 per cent, K_2O 20 per cent, or a fertilizer ratio of 3–5–2.

It is of course evident that any other percentage composition or ratio of fertilizers can likewise be represented on this diagram; for instance $33\frac{1}{3}$ per cent P_2O_5, $33\frac{1}{3}$ per cent NH_3, and $33\frac{1}{3}$ per cent K_2O

would fall on the exact center of the diagram between points 25, 32, and 33, and a mixture with the ratio 15.2–50.3–34.5 would fall between the points 42, 51, and 53. For actually locating such points the finer ruled and subdivided paper above referred to should be used.

For the sake of convenience in stating the percentage composition of the fertilizer mixtures in this investigation, the figures are always given in the order P_2O_5, NH_3, and K_2O, as shown above.

The triangle therefore represents single fertilizer constituents at the apices or vertices, mixtures of any two constituents along the boundary lines of the triangle, and mixtures of all three constituents within the triangle.

In the following table is given the composition represented by each of the 66 points in the diagram:

TABLE I.—*Sixty-six possible ratios of the three fertilizer constituents P_2O_5, NH_3, and K_2O in 10 per cent stages.*

Point No.	Ratio or percentage composition.			Point No.	Ratio or percentage composition.			Point No.	Ratio or percentage composition.		
	P_2O_5.	NH_3.	K_2O.		P_2O_5.	NH_3.	K_2O.		P_2O_5.	NH_3.	K_2O.
1	100	0	0	23	40	10	50	45	20	80	0
2	90	0	10	24	40	20	40	46	10	0	90
3	90	10	0	25	40	30	30	47	10	10	80
4	80	0	20	26	40	40	20	48	10	20	70
5	80	10	10	27	40	50	10	49	10	30	60
6	80	20	0	28	40	60	0	50	10	40	50
7	70	0	30	29	30	0	70	51	10	50	40
8	70	10	20	30	30	10	60	52	10	60	30
9	70	20	10	31	30	20	50	53	10	70	20
10	70	30	0	32	30	30	40	54	10	80	10
11	60	0	40	33	30	40	30	55	10	90	0
12	60	10	30	34	30	50	20	56	0	0	100
13	60	20	20	35	30	60	10	57	0	10	90
14	60	30	10	36	30	70	0	58	0	20	80
15	60	40	0	37	20	0	80	59	0	30	70
16	50	0	50	38	20	10	70	60	0	40	60
17	50	10	40	39	20	20	60	61	0	50	50
18	50	20	30	40	20	30	50	62	0	60	40
19	50	30	20	41	20	40	40	63	0	70	30
20	50	40	10	42	20	50	30	64	0	80	20
21	50	50	0	43	20	60	20	65	0	90	10
22	40	0	60	44	20	70	10	66	0	100	0

PREPARATION OF THE CULTURE SOLUTIONS.

As the result of preliminary tests 80 parts per million was decided upon as the concentration for the total P_2O_5, NH_3, and K_2O in these experiments. The salts used were calcium acid phosphate, sodium nitrate, and potassium sulphate. For the purpose of preparing the 66 culture solutions needed in this investigation, stock solutions of the three salts were prepared separately. The salts used were chemically pure salts, and were dissolved in each case in physiologically pure water, the preparation of which will be described on a subsequent page. For the calcium acid phosphate solution 1.7760 grams of $CaH_4(PO_4)_2.H_2O$ per liter were used. This solution has a concen-

tration of 1,000 parts per million of P_2O_5. The sodium nitrate solution was prepared by using 5.0000 grams of $NaNO_3$ per liter. This solution is equivalent to a concentration of 1,000 parts per million of NH_3. The potassium sulphate solution was prepared by dissolving 1.8520 grams of K_2SO_4 per liter. This solution has a concentration of 1,000 parts per million of K_2O.

The amount of culture solution used in each culture bottle being 250 c. c., it follows that every 2 c. c. of these 1,000 parts per million stock solutions will represent 8 parts per million in the culture solution when this is diluted to the capacity of the bottle; i. e., the successive addition of 2 c. c. of the stock solution gives the 10 per cent differences desired in putting up the 66 solutions. In putting up the 66 cultures it was found desirable to calibrate each bottle for 250 c. c. capacity and to number them consecutively from 1 to 66. Bottles in which the 250 c. c. mark was either too high or too low, thus submerging the seeds when filled, were discarded, only those being used which brought the surface of the liquid from one-half to one-fourth of an inch from the top.

These 66 bottles were then arranged in a triangular form, as illustrated diagrammatically in figure 1.

The 1,000 parts per million stock solutions above described were measured from a burette. The bottles received the solutions as follows:

Distribution of stock solutions among bottles.

CALCIUM ACID PHOSPHATE.

Bottles along line—	Amount of solution.	Bottles along line—	Amount of solution.
	c. c.		c. c.
56–66	None.	11–15	12
46–55	2	7–10	14
37–45	4	4–6	16
29–36	6	2–3	18
22–28	8	1	20
16–21	10		

SODIUM NITRATE.

1–56	None.	28–62	12
3–57	2	36–63	14
6–58	4	45–64	16
10–59	6	55–65	18
15–60	8	66	20
21–61	10		

POTASSIUM SULPHATE.

1–66	None.	22–60	12
2–65	2	29–59	14
4–64	4	37–58	16
7–63	6	46–57	18
11–62	8	56	20
16–61	10		

Each bottle received a total of 20 c. c. of one, two, or three of the solutions, depending upon whether it was at the apex, along the sides, or in the interior of the triangle.

All of the cultures were now ready for dilution up to the 250-c. c. mark.

ADDITION OF DIHYDROXYSTEARIC ACID TO THE CULTURE SOLUTIONS.

In this investigation, as already mentioned, a culture solution containing 50 parts per million of dihydroxystearic acid was to be used. The amount of this acid to be added to each culture bottle of 250 c. c. was therefore 12.5 milligrams. Of the 250 c. c., 20 c. c. were already contained in the bottles in the form of the fertilizer salt solution. Therefore the dihydroxystearic acid solution with which the fertilizer salt solution in the bottles was to be diluted consisted of 12.5 milligrams of the acid dissolved in 230 c. c. of water. A sufficient quantity of this solution was prepared to fill the 66 bottles.

PREPARATION OF A CONTROL SET.

As a means of comparing the cultures grown in these solutions containing dihydroxystearic acid, it was necessary to put up cultures prepared in exactly the same way, except that instead of making up to 250 c. c. with the dihydroxystearic acid solution, physiologically pure water was used. The culture solutions were now ready to receive the plants which were thereafter grown in a greenhouse under suitable conditions. The manner of growing the seedlings and the method of inserting them in the solutions will be described presently.

CHANGING THE SOLUTIONS.

As already mentioned, these solutions were changed every three days. This was done by putting up other triangles of bottles similar in every respect to the ones just described. The corks with the plants were then transferred from the old solution to the corresponding new solution. Since the old solution had lost some water by transpiration, it was again made up to 250 c. c. and tightly stoppered, and was now ready for analysis. The amounts of phosphate, nitrate, and potash were determined by the methods described in another section. Three days later a similar change was made, and so on every three days to the termination of the experiment.

DETERMINATION OF GREEN WEIGHT OF CULTURES.

At the expiration of twenty-four days, during which eight changes of the culture solutions had been made, the green weight of the tops was taken. This was done by drawing up the plants until the now exhausted seed was close to the lower surface of the cork and with a sharp knife severing the tops, which could then be pulled through the openings in the cork. The tops were immediately weighed on a chemical balance, the weight being determined to the third decimal place.

SOLUTION-CULTURE METHOD.

Before proceeding with a description of the general appearance of the cultures growing in solutions with different fertilizer combinations with and without dihydroxystearic acid, it may be well to describe briefly here the solution-culture method used in these experiments, as the manner of procuring a sufficiently large number of seedlings and the method of preparing physiologically pure water are important factors in carrying on this or allied investigations.

METHOD OF PROCURING UNIFORM SEEDLINGS.

In the work under consideration, as well as in other work in progress in these laboratories, it is necessary to have a large number, often several hundred, and sometimes thousands, of uniform seedlings, i. e., seedlings of the same age and equal in development and general vitality. The general principle on which this equal germination of wheat seedlings is based has already been described by Livingston[a] and in former bulletins of this bureau.[b] The method consists in having a perforated disk, supported by ordinary corks in such a way that it will just float upon the surface of a pan of water. In the earlier work a wire gauze, which had been coated with paraffin so as to make virtually a plate of paraffin reinforced by wire, was used, holes being made in this plate by means of a hot wire. Perforated cork sheets, preferably paraffined, have also been used. In this case sheet cork about one-eighth of an inch in thickness is immersed in melted paraffin, and, after removal from the paraffin, this is allowed to harden in the air spaces of the cork. Holes are then made by means of a small cork borer, so as to give a perforated plate. Both of these plates are open to objections. In the paraffined wire-gauze plate, when used continually, there is a tendency for the paraffin to split off from the wire, which is thus exposed to the action of the water and the roots; moreover, this plate is not easily repaired. The cork plate, on the other hand, shows considerable tendency to warp, is rather fragile, and is not easily kept sterile.

Instead of these plates there were used in the present experiments perforated hard-rubber sheets, thus overcoming the above objections to a considerable degree. These are prepared by cutting a circular disk of 305 mm. diameter from vulcanized sheet rubber 3.2 mm. in thickness. By clamping several of these tightly together, preferably between layers of wood, small holes are drilled through the mass approximately 4.8 mm. in diameter and 5 mm. apart. Disks of this material float level upon the water when supported by corks, are not so subject to warping, and are readily cleaned and kept sterile. The corks are fastened to the under surface of the disk in four or five places on the circumference and in the center by means of rubber or wooden

[a] The Plant World, **9**, 13 (1906). [b] Bulletin 40.

pegs or wire. If wire is used, it should be made either of iron or aluminum, never of brass or copper. The size of the corks is so gauged by trial that the disk is just supported on the surface of the water. This apparatus is shown in Plate I, figure 1. After floating this perforated disk on the surface of the water the wheat seed, which has been previously soaked for about two hours, not longer, is spread evenly over the surface. This method insures an even germination of the seed and has the advantage of keeping the seed and later the young seedlings just moist. The seeds never lie beneath the water, nor do they remain suspended dry above the water. The roots grow through the holes of the disk into the liquid below. This method of sprouting wheat seedlings is far superior to growing them in sand, since the seedlings are more uniform and the apparatus can be kept sterile much more readily than sand. Furthermore, for water-culture purposes the seedling is readily removed by merely lifting it from the disk. In this way the roots or delicate root hairs suffer no injury whatever, while in removing seedlings from sand some injury is unavoidable. Moreover, the seedlings are removed direct from water to grow in solutions, and thus have the advantage of germination in a medium similar to that in which they are to be grown.

More recently disks of perforated aluminum have been used in this laboratory and have proven very satisfactory. These disks are floated by means of a raft of sealed glass tubing of such dimensions as is required to float the plates in the manner above described. Three lengths of tubing 102 centimeters long, 35 millimeters in diameter, with approximately a 1.5-millimeter wall thickness have been found to be necessary to float six aluminum disks 30 centimeters in diameter and 1.6 millimeters in thickness. The lengths of sealed tubing are wired together into a raft by means of aluminum wire, glass rods 56 centimeters long and 12 millimeters in diameter serving as crosspieces. The entire arrangement is floated in a porcelain-lined iron tank. Plate I, figure 2, shows this tank with seedlings at various stages of development.

The water in the germinating pans may be distilled water, if desired, or where good tap water can be secured this may be used. The water in the pans is changed daily or, during the warm weather, twice a day. Several hundred uniform seedlings can be procured from a single disk of the kind described. Whatever inferior plants occur are rejected. For the bottle-culture work described in this bulletin the seedlings were used when the plumule was about 1 inch high and just ready to emerge from the enveloping sheet.

NOTCHING CORKS AND MOUNTING SEEDLINGS.

The bottles used in these cultures are made of flint glass, have a capacity of about 250 c. c., a total height of 100 mm., an outside

diameter of 70 mm. at the bottom, a neck about 20 mm. high, and a mouth 57 mm. in diameter. This bottle is stoppered by means of a soft, flat cork about 12 mm. in thickness and notched for holding the seedlings. The method of notching these corks consists in cutting 10 vertical, triangular wedges from its circumference. Each wedge after being cut out is truncated, so that when replaced a small triangular opening is formed, through which the plumule of the seedling will pass. This hole should be large enough to hold the seedling firmly and yet not bruise or injure it in any way by pressure. Around the circumference of the cork, in the upper half, a groove is made sufficiently large to hold a small rubber band. After the wedges are inserted, the band keeps them in place and allows the cork with the seedlings to be handled readily and put into or taken out of the bottle without disturbing the plants. The seedlings are most easily inserted in the cork in the following manner: The cork with the 10 wedges held in place by the rubber band is taken in the left hand and the seedlings in the right hand; the plumule is pushed through the small triangular opening, and then pulled up until the seed is close against the cork. When older seedlings, in which the leaves have unfolded themselves, are to be used for an experiment or where plants such as cowpeas are used, the wedge must be removed, the seedling then put in place, and the wedge and rubber band replaced.

PREPARATION OF PHYSIOLOGICALLY PURE DISTILLED WATER.

It is safe to say that ordinary distilled water, such as is commonly found in laboratories, is unsuited for culture experiments. This is due to a variety of causes which need not be entered into here, but which are discussed in a previous bulletin.[a] Such water, while pure from a chemical and physical standpoint, is nevertheless not suited for such delicate indicators as plants, which are highly susceptible even to very minute quantities of toxic materials. Such water can be improved by distillation with strong oxidizing agents, such as potassium permanganate in alkaline solution or potassium bichromate in acid solution. A far simpler method, however, and one which has always given very satisfactory results in these laboratories, is to purify the water by shaking it with a highly absorptive carbon black, which removes from the water any traces of injurious bodies it may contain. Not all carbon black possesses this property to an equal degree; the variety used in this laboratory is known as the "G Elf" brand, and is prepared on a commercial scale by burning natural gas and condensing the finely divided carbon on cooled surfaces. It is the same carbon black used and described in Bulletin 31 for the purpose of decolorizing soil and plant solutions. For the present purpose the carbon black is thoroughly washed with distilled water

[a] Bul. 36, Bureau of Soils, U. S. Dept. Agr.

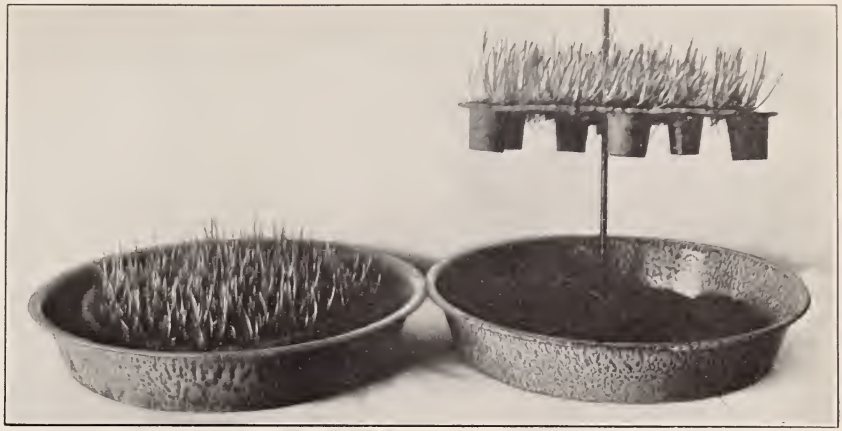

FIG. 1.—SHOWING THE METHOD OF GERMINATING WHEAT SEEDLINGS ON A PERFORATED PLATE. THE PLATE ON THE RIGHT IS ELEVATED TO SHOW THE CORKS AND ROOTS.

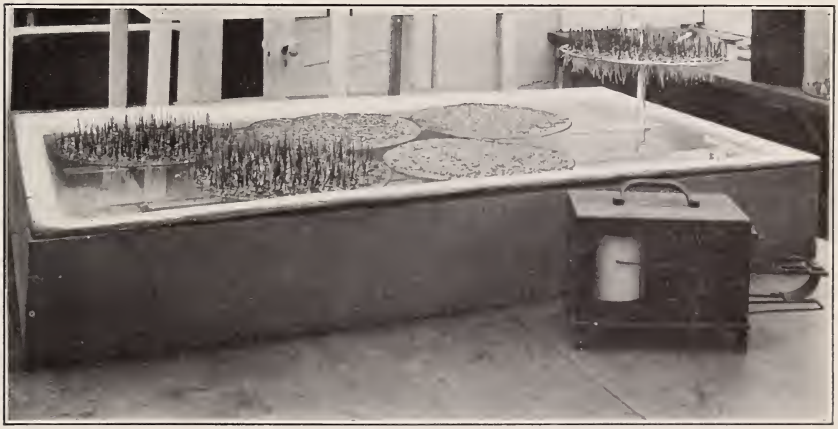

FIG. 2.—SHOWING THE METHOD OF GERMINATING MANY THOUSAND SEEDLINGS ON PERFORATED ALUMINUM PLATES FLOATED ON THE SURFACE OF WATER BY MEANS OF A SEALED GLASS-TUBE RAFT IN A PORCELAIN-LINED TANK.

as an added precaution, although it is not definitely known whether or not anything is thereby removed from it. The carbon black is then kept in this moist condition mixed with water so as to form a thin paste. About 10 c. c. of this paste is added to each liter of water which is to be purified and, after shaking, the mixture is allowed to stand for fifteen to thirty minutes and is then filtered through an ordinary filter paper into a clean hard-glass receptacle. Water so treated is very satisfactory for the growth of plants in solution cultures.

GENERAL APPEARANCE OF THE CULTURES IN SOLUTIONS CONTAINING DIFFERENT FERTILIZER RATIOS, WITH AND WITHOUT DIHYDROXYSTEARIC ACID.

The plants in the different culture solutions prepared show some marked differences almost from the very outset. After several changes of solution have been made, these differences become quite prominent. The most marked of these is that the solutions containing only one or two of the fertilizer ingredients, i. e., those along the entire periphery of the triangle, show a markedly less development of the plants than the cultures in the interior of the triangle, wherein the three elements are combined. In other words, even the addition of only 10 per cent of the third element to mixtures of the other two produces a very appreciable increase in plant growth. This effect is most noticeable in the change from no nitrate to 10 per cent of nitrate. Of the single fertilizer ingredients, the nitrate culture is the best and this is usually followed by the potassium culture, the phosphate culture being in general the poorest of the entire triangle. The cultures in the interior of the triangle do not show such marked differences, although it is apparent that there is a tendency toward a rise in the middle of any line, this being displaced somewhat along some of the lines so as to give the effect of the highest and best region of growth lying in the middle of the lower part of the triangle, i. e., nearer to the potassium-nitrogen base.

These general tendencies in the growth of the cultures as seen in the triangle are the same whether dihydroxystearic acid is present or not. In general, however, the single elements, as well as combinations of two, show an even greater difference in comparison with the interior of the triangle than was the case where the dihydroxystearic acid was absent, thus indicating that the better conditions for plant growth offered in the interior of the triangle tended to diminish the harmful effect of this body. In fact, some of the plants along the periphery of the triangle were unable to withstand the repeated treatments for the entire period of growth and were dead when the experiment ended. This was never the case in the interior, although strongly marked inhibitive effects were evident here also as the comparison

given below will show. The difference between the cultures in solutions containing the dihydroxystearic acid and in those without this substance is very marked in nearly all cases, and the difference in appearance of the entire triangles with and without this substance is very striking.

In addition to the general appearance of the tops, the presence of this harmful body produces other effects readily recognized by the investigator and forming on the whole a better physiological indicator of the toxicity than the growth of tops, as has been well recognized by physiologists generally in conducting similar work. Reference is here made to the action of the body on root condition and growth. The root being bathed by the solution and being moreover the delicate mechanism of absorption, is often a more sensitive indicator than is the growth of the top. The most marked effects of dihydroxystearic acid on roots is strongly to inhibit their growth and to produce enlarged or swollen tips, which are frequently very dark in color and often turned back in the form of hooks. These phenomena are observed even when the injury is not so great as to kill the plants. This action of the body on the roots is influenced by the conditions of growth imposed upon the plant by the different fertilizer ratios. This is shown by the following general notes taken on one of these sets one week after growth in the cultures had begun:

All the plants in the solutions having no nitrogen appear to be dying. The roots are already dead, have made little growth and are much discolored, the tips dark and swollen and a large number turned upward. The tops have made some growth; some of the leaves are curled, but most are still fresh and green.

The plants in the solutions containing no phosphate are similar to the above; the roots and tops are somewhat better, but still show an undoubted harmful action, the roots being dark and flimsy, tips swollen and often turned upward, the greater number being dead.

The plants in the solutions on the potash base line are better than the two sets described above. The upper parts of the roots of these plants are dark, the lower sections that have recently grown out are white and clear, but the tips are still dark and swollen, and many are turned upward.

The plants in the interior of the triangle, where all three fertilizer ingredients are present, are fairly good, with no great difference noticeable at this stage, but the best plants occur near the center. The roots, on the other hand, are already showing differences. They are rather poor along the line having 8 parts per million of NH_3. The upper and older part of the roots is dark, the newer portion is white and clear, but the tips are swollen. The general condition of the roots as a whole is a great deal better than in the case of those in the boundary line of the triangle. The condition of the roots on the

line having 8 parts per million P_2O_5 and on the line having 8 parts per million K_2O are about the same as on the 8 parts per million NH_3 line.

Farther within the triangle the general condition of the roots is much better. The solutions in cultures number 25, 32, 33, 34, 42, and 43 show by their roots that the harmful effect of the substance has been somewhat overcome; they are lighter than the others; in fact most of the roots, except the upper and older sections, are white and clear, but the tips are still slightly swollen and somewhat bent.

Another property of the roots which is influenced by harmful bodies is that of root oxidation. It has been shown in a former paper [a] that plant roots possess a very appreciable power of oxidation and that this power is stronger in good soils than in poor, or in their extracts, and that harmful bodies retard this root oxidation, and beneficial bodies augment it. Fertilizer salts were there shown to increase root oxidation, and through this action a reduction in the quantity of the harmful body present was produced.

Some further observations were made in connection with the present investigation in regard to oxidation and the effect of dihydroxystearic acid upon this function. The effect was so marked in the concentrations used, namely 50 parts per million, that the roots at the end of the experiment were found to be almost wholly lacking in ability to oxidize aloin used as an indicator in the manner described in the publication referred to above. Some oxidizing power was still possessed by the cultures in the interior of the triangle, where, as mentioned above, the growth was better than in other regions, although even here the power of oxidation was greatly impaired. Nevertheless, it is interesting to note that the conditions which produced the best general development of the plants are closely associated with a power of root oxidation. Lower concentrations of dihydroxystearic acid would doubtless be better suited for a more thorough study of this matter.

Some of the plants grown in solutions with and without dihydroxystearic acid are shown in the accompanying plates. The cultures taken are those containing the fertilizer elements alone; those containing mixtures of equal parts of any two of them; some others lying in the interior of the triangle, selected to represent as nearly as possible a fertilizer rich in phosphoric acid, one rich in nitrate and one rich in potash. The results shown in these illustrations are representative of the general effect over all the region of the triangle from which they are taken.

In the three figures of Plate II are shown the comparative effects of dihydroxystearic acid when the single fertilizer salts are present.

[a] Bul. 56, Bureau of Soils, U. S. Dept. Agr.

These show the marked effect of this substance on root development, as well as on the growth of tops. They also show that the effect was perhaps the least marked in the case of nitrate and the most marked in the case of phosphate.

Plate III, figures 1, 2, and 3, shows the effect of any two of the salts in combination in equal proportions. The nitrogen and phosphate combination gives the best growth and the least injury to both tops and roots when dihydroxystearic acid is present, although this combination is by no means able entirely to overcome the inhibitive effects.

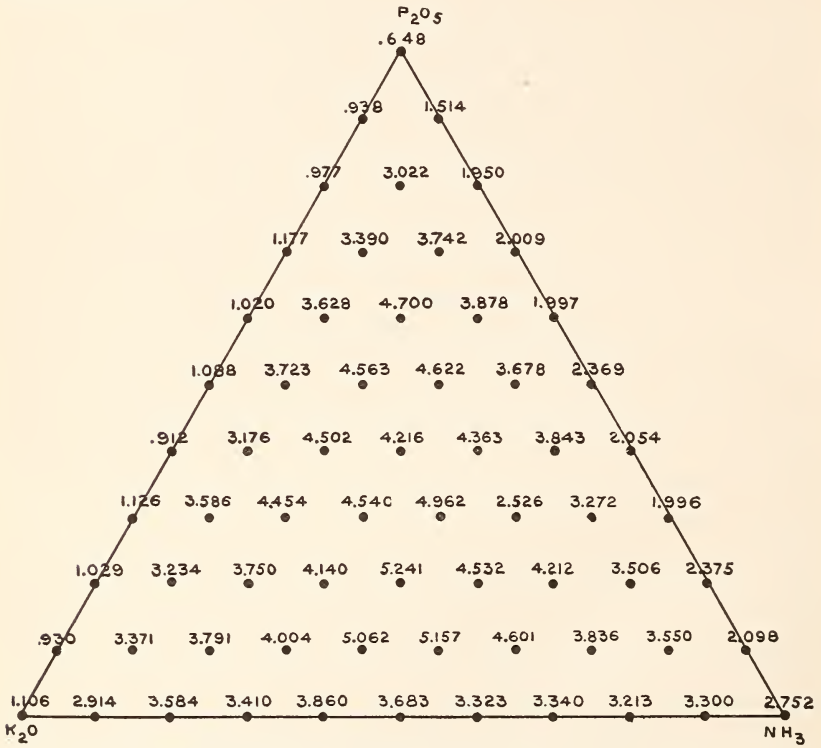

FIG. 2.—Green weight of 66 cultures, with different proportions of P_2O_5, NH_3, and K_2O, without dihydroxystearic acid—Experiment I.

Plate IV, figures 1, 2, and 3, shows three of the cultures from within the triangle where all three fertilizer ingredients were present in different ratios. In this case the better growth and the lesser inhibitive effect are shown by the culture given in figure 2.

GREEN WEIGHT OF THE VARIOUS CULTURES OF EXPERIMENT I.

The green weights given for the 66 cultures in the triangular diagram shown in figure 2 are those of the solutions in which no

dihydroxystearic acid was present and in figure 3 those of the solutions in which 50 parts per million of dihydroxystearic acid was present. Inasmuch as analyses of culture solutions had to be made every three days for the three different ingredients, it was not possible to analyze more than one triangle containing 66 solutions at one time, the laboratory facilities being inadequate to handle in three days the 396 separate determinations necessary to complete the two sets. These first complete sets of 66 cultures each, with and without dihydroxystearic acid, were therefore grown and analyzed separately. The set grown without the dihydroxystearic

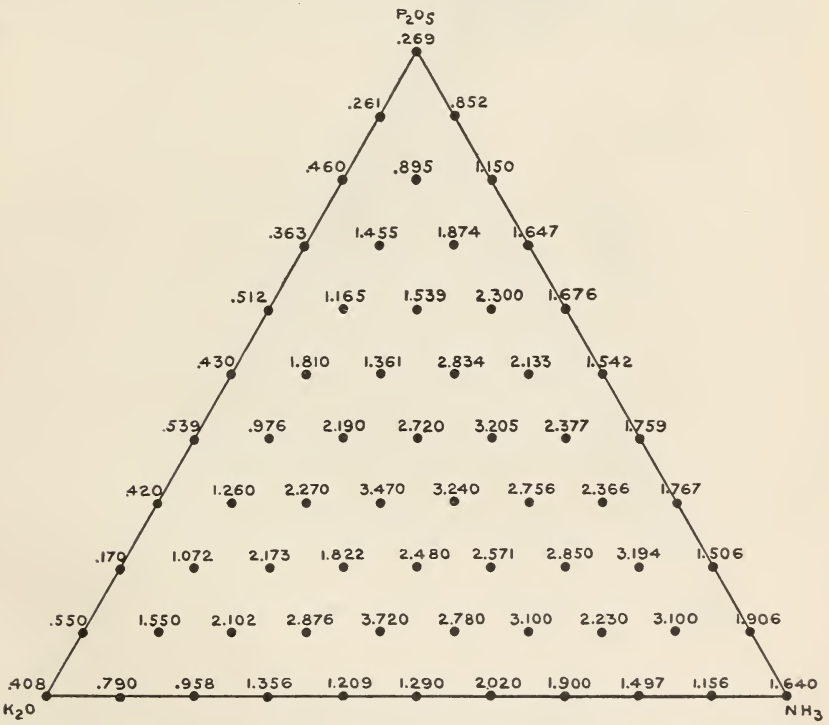

FIG. 3.—Green weight of 66 cultures, with different proportions of P_2O_5, NH_3, and K_2O, with dihydroxystearic acid—Experiment I.

acid grew from February 25 to March 21 and the set with the dihydroxystearic acid grew from April 2 to April 26. While these two sets are not strictly comparable, owing to the fact that they were grown at different times, though under very similar greenhouse conditions and for the same length of time as well as in the same time of year, one closely following the other, they show nevertheless very strikingly the effect of the dihydroxystearic acid, the effects being essentially the same as those already shown in Plates II to IV, which were taken from sets grown simultaneously. It will be seen

that in both triangles the growth with the single elements or along the lines where mixtures of two occurred was in general less than within the triangle. The region of greatest growth in the solutions without the dihydroxystearic acid was approximately in the middle of the 10 and 20 per cent phosphate lines. In the dihydroxystearic acid cultures it might be said in general that this point of greater growth was displaced along these lines toward the nitrogen side.

The total growth made in the 66 cultures without the dihydroxystearic acid was 207 grams as against 114 grams in the case of the 66 cultures with the 50 parts per million of dihydroxystearic acid, or

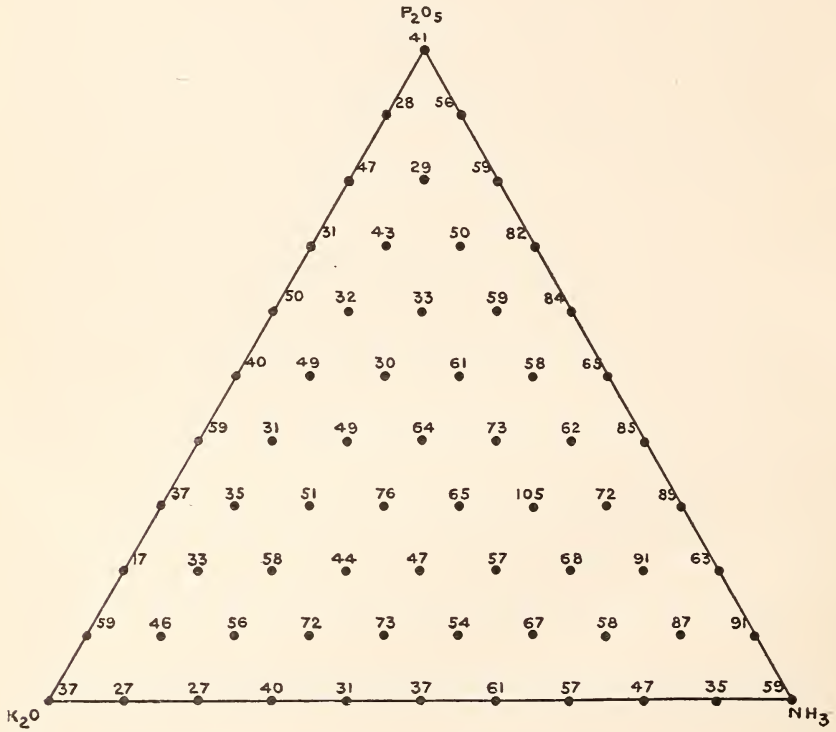

FIG. 4.—Showing the decrease in growth due to dihydroxystearic acid, when growth of the cultures without this organic constituent equals 100—Experiment I.

putting the first as 100, the latter becomes 55. In other words, the plants with the dihydroxystearic acid made only, as an average of the 66 cultures, a growth of 54 per cent. The individual relative growth for each culture is given in the diagram, figure 4. From this it will be seen that the harmful substance produced its greatest effect in general along the periphery of the triangle, except perhaps along the phosphate-nitrogen line. In the interior of the triangle, where the greater growth occurred under more normal conditions, the depression caused by the substance was not so marked, and this

seems to be especially true in the region nearer to the nitrate end, in which, as already pointed out, the greater growth occurred in the cultures where the dihydroxystearic acid was present. A more detailed discussion, as well as grouping of these green weights and their correlation with the concentrations of the solutions and amounts of materials removed, will be given later.

TOTAL CONCENTRATIONS IN P_2O_5, NH_3, AND K_2O FOUND IN THE VARIOUS CULTURE SOLUTIONS OF EXPERIMENT I.

As has already been stated, the solutions were analyzed every third day for the three component fertilizer parts, phosphate, nitrate,

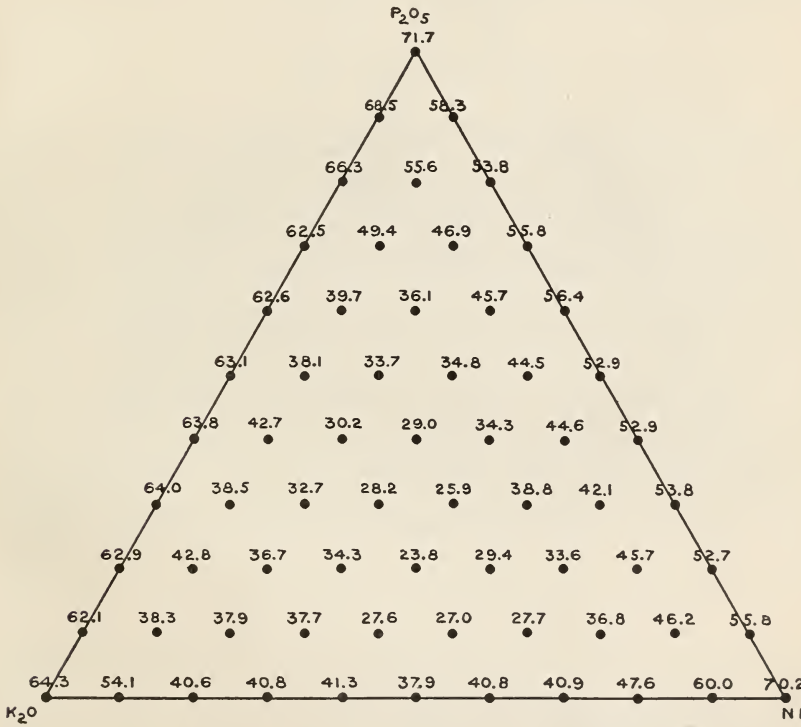

FIG. 5.—Showing the average concentration of the solution, in parts per million of $P_2O_5 + NH_3 + K_2O$, after growth of wheat plants, without dihydroxystearic acid—Experiment I.

and potassium, expressed as P_2O_5, NH_3, and K_2O. The original concentration in these elements was in the sum total 80 parts per million. After analysis, the sum total of the three component parts was again calculated, and the average concentration of these three elements was ascertained for the eight periods. These average concentrations will be found in the diagram in figure 5, which gives the concentration of the solution when no dihydroxystearic acid was

present, and in figure 6, which gives the concentration of the solution when dihydroxystearic acid was present. It will be seen that in practically all cases where dihydroxystearic acid was present the concentration of the solution was not reduced as much as in the corresponding solution without dihydroxystearic acid. A more detailed discussion of these results and their component parts will be given later.

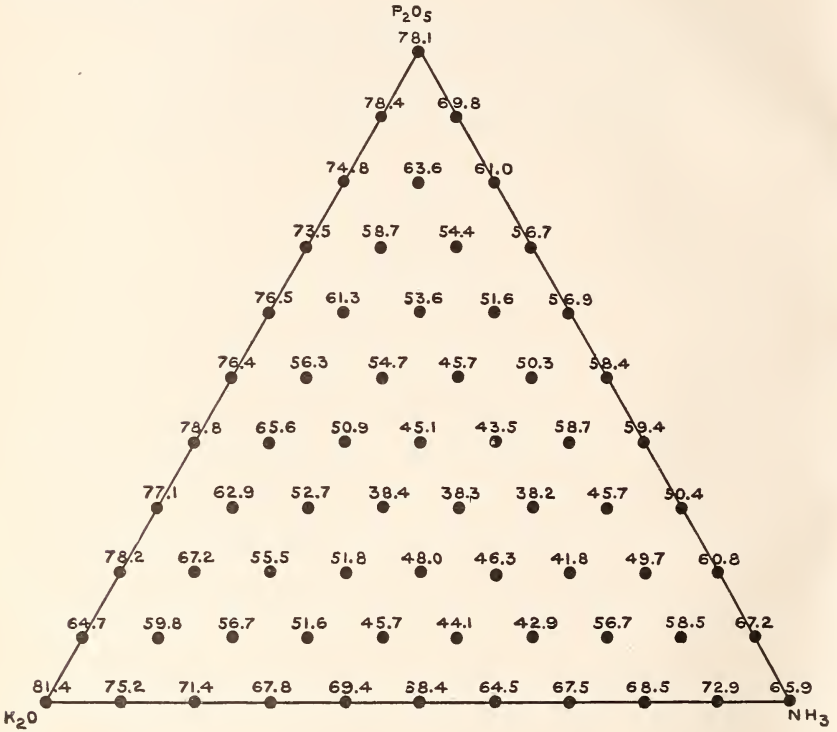

FIG. 6.—Showing the average concentration of the solution, in parts per million of $P_2O_5 + NH_3 + K_2O$, after growth of wheat plants, with dihydroxystearic acid—Experiment I.

RATIOS OF P_2O_5, NH_3, AND K_2O FOUND IN THE VARIOUS CULTURE SOLUTIONS OF EXPERIMENT I.

Table II gives the ratios of P_2O_5, NH_3, and K_2O found in the various culture solutions of Experiment I. In the second column are given the original ratios; in the third and fifth, the average ratios found by analysis to exist in the solutions during the eight periods, without and with dihydroxystearic acid, respectively; the fourth and sixth columns give the ratios of the removed material, respectively.

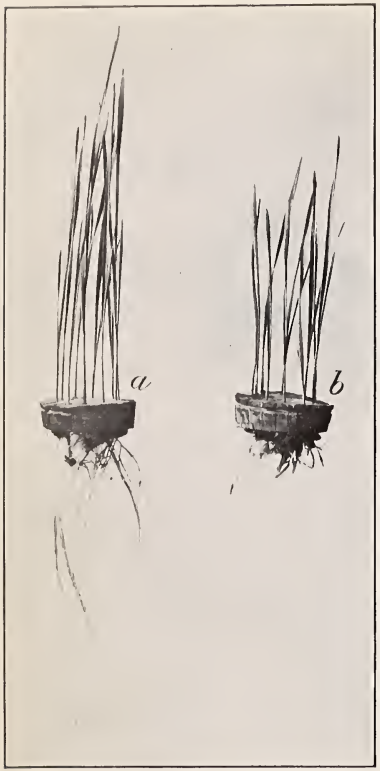

FIG. 1.

Wheat plants growing in culture solutions containing a fertilizer mixture composed of phosphate 100 per cent, nitrogen 0 per cent, potash 0 per cent: *a*, without dihydroxystearic acid; *b*, with dihydroxystearic acid.

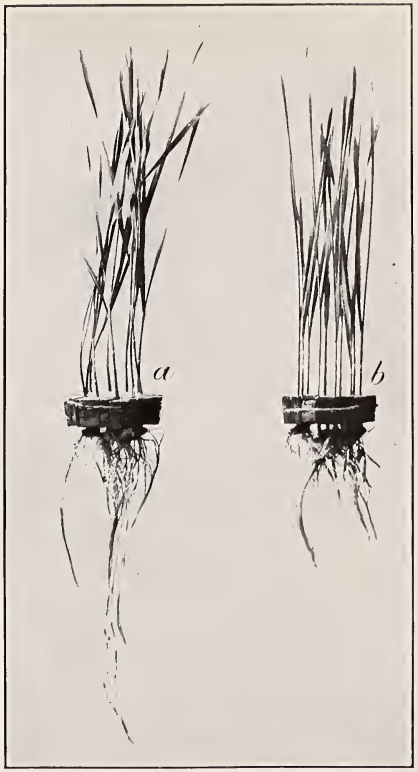

FIG. 2.

Wheat plants growing in culture solutions containing a fertilizer mixture composed of phosphate 0 per cent, nitrogen 100 per cent, potash 0 per cent: *a*, without dihydroxystearic acid; *b*, with dihydroxystearic acid.

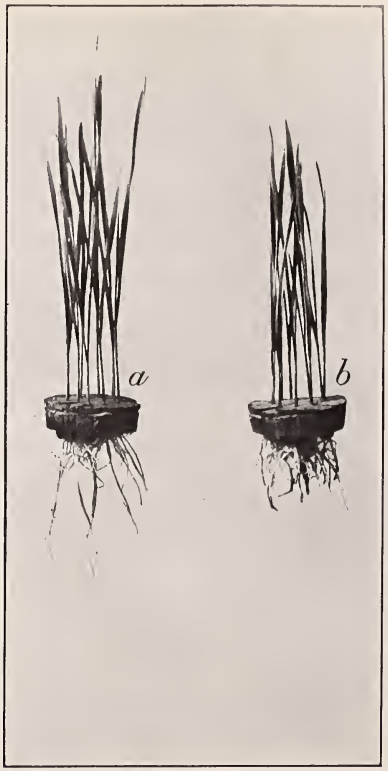

FIG. 3.

Wheat plants growing in culture solutions containing a fertilizer mixture composed of phosphate 0 per cent, nitrogen 0 per cent, potash 100 per cent: *a*, without dihydroxystearic acid; *b*, with dihydroxystearic acid.

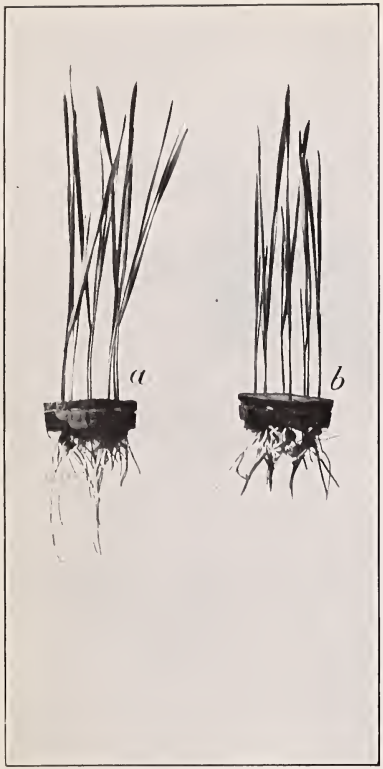

FIG. 1.

Wheat plants growing in culture solutions containing a fertilizer mixture composed of phosphate 50 per cent, nitrogen 0 per cent, potash 50 per cent: *a*, without dihydroxystearic acid; *b*, with dihydroxystearic acid.

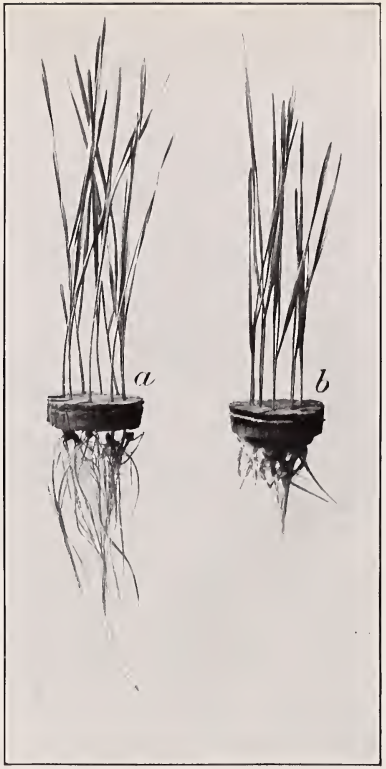

FIG. 2.

Wheat plants growing in culture solutions containing a fertilizer mixture composed of phosphate 50 per cent, nitrogen 50 per cent, potash 0 per cent: *a*, without dihydroxystearic acid; *b*, with dihydroxystearic acid.

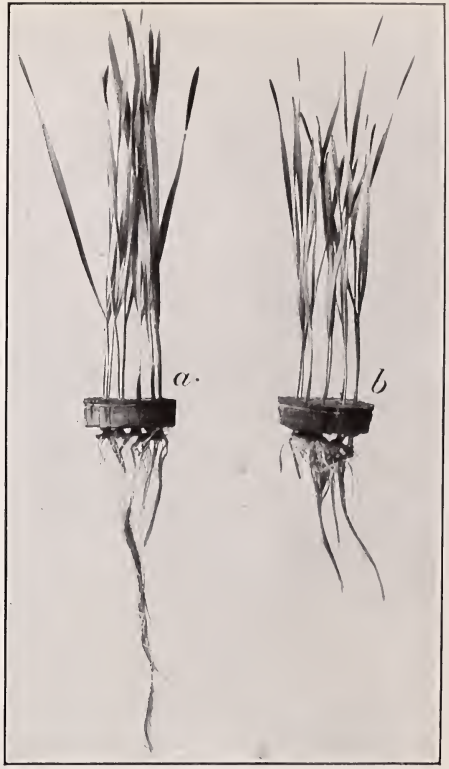

FIG. 3.

Wheat plants growing in culture solutions containing a fertilizer mixture composed of phosphate 0 per cent, nitrogen 50 per cent, potash 50 per cent: *a*, without dihydroxystearic acid; *b*, with dihydroxystearic acid.

TABLE II.—*Showing the ratios of the average amounts of P_2O_5, NH_3, and K_2O left in the 66 culture solutions and the ratios of the material lost from the solutions during Experiment I, together with the original ratios of these constituents.*

Culture No.	Original ratio of culture solution in—			Without dihydroxystearic acid.						With dihydroxystearic acid.					
				Final ratio in the solution.			Ratio of the loss from the solution.			Final ratio in the solution.			Ratio of the loss from the solution.		
	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.
1	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0
2	90	0	10	94	0	6	65	0	35	91	0	9	64	0	36
3	90	10	0	100	0	0	63	37	0	99	1	0	24	0	76
4	80	0	20	89	0	11	38	0	62	81	0	19	58	0	42
5	80	10	10	95	0	5	46	33	21	90	0	10	42	49	9
6	80	20	0	94	6	0	51	49	0	97	3	0	29	71	0
7	70	0	30	78	0	22	42	0	58	71	0	29	62	0	38
8	70	10	20	95	0	5	35	24	41	84	0	16	31	37	32
9	70	20	10	95	0	5	35	49	16	90	2	8	28	58	14
10	70	30	0	80	20	0	46	54	0	88	12	0	27	63	0
11	60	0	40	68	0	32	36	0	64	62	0	38	27	0	63
12	60	10	30	93	0	7	28	19	53	70	0	30	26	42	32
13	60	20	20	93	0	7	32	36	32	80	2	18	20	54	26
14	60	30	10	83	12	5	32	51	17	82	8	10	20	70	10
15	60	40	0	69	31	0	35	65	0	74	26	0	25	75	0
16	50	0	50	54	0	46	37	0	63	50	0	50	39	0	71
17	50	10	40	79	1	20	24	18	58	62	2	36	21	31	48
18	50	20	30	84	1	15	27	33	40	65	3	32	18	57	25
19	50	30	20	78	15	7	28	41	31	73	10	17	19	57	24
20	50	40	10	64	31	5	33	51	16	70	23	7	17	67	16
21	50	50	0	54	46	0	40	60	0	62	38	0	16	84	0
22	40	0	60	42	0	58	32	0	68	38	0	62	50	0	50
23	40	10	50	52	2	46	25	21	54	43	1	56	25	49	26
24	40	20	40	66	0	34	24	32	44	52	3	45	18	50	32
25	40	30	30	71	14	15	22	40	38	58	12	30	16	53	31
26	40	40	20	58	33	9	26	45	29	60	25	15	17	57	26
27	40	50	10	49	44	7	29	56	15	47	45	8	18	67	15
28	40	60	0	44	56	0	31	69	0	47	53	0	21	79	0
29	30	0	70	32	0	68	21	0	79	30	0	70	29	0	71
30	30	10	60	43	0	57	17	19	64	34	0	66	18	43	39
31	30	20	50	42	0	58	21	34	45	36	3	61	18	52	30
32	30	30	40	50	14	36	19	38	43	46	9	45	15	48	37
33	30	40	30	50	36	14	21	42	37	47	20	33	14	58	28
34	30	50	20	44	44	12	17	58	28	49	33	18	13	66	21
35	30	60	10	37	56	7	23	63	14	42	50	8	14	72	14
36	30	70	0	35	65	0	20	80	0	41	59	0	11	89	0
37	20	0	80	21	0	79	15	0	85	18	0	82	22	0	78
38	20	10	70	23	0	77	16	21	63	21	1	78	12	55	33
39	20	20	60	24	0	76	16	37	47	23	5	72	13	53	34
40	20	30	50	27	18	55	15	40	45	25	13	62	11	60	29
41	20	40	40	26	39	35	15	41	44	28	27	45	10	58	32
42	20	50	30	26	52	22	16	48	36	29	40	31	9	63	28
43	20	60	20	23	67	10	18	55	27	29	53	18	10	67	23
44	20	70	10	19	73	8	21	66	13	24	67	7	13	74	13
45	20	80	0	19	81	0	20	80	0	23	77	0	10	90	0
46	10	0	90	12	0	88	4	0	96	12	0	88	0	0	100
47	10	10	80	9	0	91	11	18	71	12	2	86	6	34	60
48	10	20	70	5	1	94	13	38	49	11	4	85	8	52	40
49	10	30	60	7	16	77	13	42	45	10	11	79	10	63	27
50	10	40	50	8	36	56	11	42	47	11	26	63	10	59	31
51	10	50	40	6	57	37	12	46	42	12	39	49	7	64	29
52	10	60	30	7	74	19	12	52	36	13	55	32	7	63	30
53	10	70	20	6	82	12	13	60	27	12	68	20	6	73	21
54	10	80	10	4	88	8	17	70	13	9	85	6	13	67	20
55	10	90	0	6	94	0	18	82	0	12	88	0	8	92	0
56	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100
57	0	10	90	0	1	99	0	28	72	0	4	96	0	68	32
58	0	20	80	0	2	98	0	38	62	0	11	89	0	76	24
59	0	30	70	0	15	85	0	45	55	0	23	77	0	66	34
60	0	40	60	0	30	70	0	51	49	0	33	67	0	77	23
61	0	50	50	0	45	55	0	54	46	0	44	56	0	85	15
62	0	60	40	0	64	36	0	54	46	0	60	40	0	61	39
63	0	70	30	0	80	20	0	56	44	0	70	30	0	81	19
64	0	80	20	0	90	10	0	66	34	0	80	20	0	81	19
65	0	90	10	0	93	7	0	80	20	0	88	12	0	92	8
66	0	100	0	0	100	0	0	100	0	0	100	0	0	100	0

It might be said that in all cases, either with or without dihydroxystearic acid, the ratio in the final solution was never the same as the original ratio. The amount of change, however, which had taken place was markedly different in the different solutions and depended largely upon what the original ratio was. In order to show this change in ratio of the fertilizer ingredients, the triangular diagram is of the greatest service, for without this it would be impossible to get an intelligent idea of what had occurred in the solution. In the diagram, figure 7, are shown the original ratios of the fertilizer constituents, the ratios left in these solutions as found by analysis,

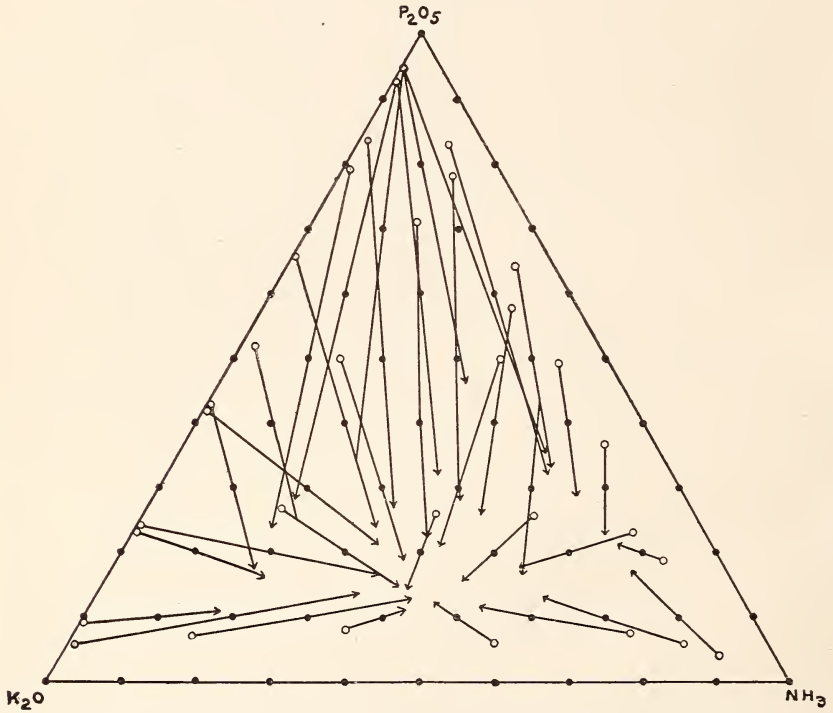

FIG. 7.—Showing the ratios of P_2O_5, NH_3, and K_2O in the original solutions, those in the solutions after growth, and those of the loss from the culture solutions, without dihydroxystearic acid—Experiment I.

and the corresponding ratio of the lost material. It may be mathematically shown that these three points lie upon a straight line and this is the case in the diagram.

Reference should again be made to the fact that every point within the diagram represents a ratio of the three fertilizer ingredients. In constructing this diagram, the ratio of the original solution is readily located and is indicated by a black dot. The ratio of the P_2O_5, NH_3, and K_2O left in the solution after growth as determined by analysis is then located in the proper place in the diagram according to the principle explained on pages 18–19 and is

indicated by a small circle. Similarly the ratio corresponding to the removed material is located and represented by an arrow point. The line connecting the three points is then drawn to indicate the various ratios relating to one and the same culture. It must be borne in mind that this diagram deals only with the ratios of the ingredients and not with the amounts that are present.

It is apparent that there is a decided tendency for these lines to converge toward a region somewhat below the center, as shown by the congregation of arrow points in this region. In other words, the solutions near this central area change least in their ratio, and the farther the ratios were removed from this central area originally the more were they altered in the course of the experiment. According to the diagram this area would seem to lie between the 10 and 20 per cent phosphate line, since the points on the lower line have moved in a direction opposite to that taken by the ratios in the upper part of the triangle. The data already presented show in general that the area of greatest growth occurred in this same region.

The facts brought out by this diagram might be stated as follows: That plant growth has disturbed the original ratio least in the lower central area is indicated by the shortness of the lines. That plant growth has disturbed the original ratio most at points nearer the angles (especially the P_2O_5 angle) is indicated by the length of the lines. The fact that the lines show a tendency to converge toward the lower central area shows that the plants have removed the fertilizer from the solutions at all points in ratios approximating those which existed in the original solutions placed in the lower central region. In other words, the original ratios of this lower central region were more nearly normal, or in harmony with the requirements of the plants; and hence the plants, in endeavoring to satisfy their needs from solutions having more unbalanced ratios, removed the fertilizers in ratios approximating this normal, thus leaving the ratios in the solutions where they grew still more unbalanced than at first.

This diagram, it must be remembered, represents the average condition during the entire period of the experiment. It is interesting to note in this connection that when the results are considered in the separate periods, in the very earliest period these ratio lines point, on the whole, lower down to an area lying between the zero and the 10 per cent phosphate line. After the first period or two the condition shown by this diagram of the average of all the periods exists. The reasons for this are discussed later, when the effect of the successive periods is presented.

In figure 7, and similar figures which appear farther on, only the cultures located within the triangle are represented, because, in case of the solutions located on the marginal lines of the triangle, the points representing the three ratios and lines connecting them would all fall on these marginal lines.

Attention might also be called to the fact that in the ratios where the nitrate was low there has been a movement to the no-nitrate line, or at least so close to this line that it was impossible to plat them otherwise. After the comparatively small amount of nitrate was removed or reduced to a minimum, the point marking the ratio would have to move along the no-nitrate base line in either the direction of the potash or of the phosphate, depending upon which was removed in the larger amount. The diagram shows that this movement of the ratio in the solutions was in nearly all cases toward the phosphate apex of the triangle. It is obvious that such a condition of affairs will cause a shifting of the lines connecting the

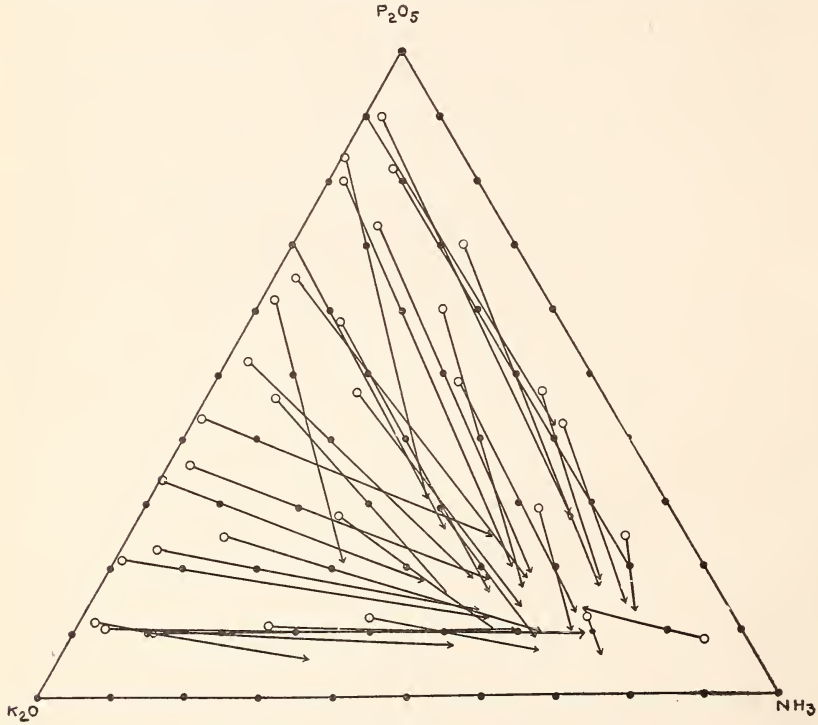

FIG. 8.—Showing the ratios of P_2O_5, NH_3, and K_2O in the original solution, those in the solution after growth and those of the loss from the culture solutions, with dihydroxystearic acid—Experiment I.

ratios in the diagram, and that a similar state of affairs in the cultures on the lower potassium line would produce a shifting of the ratio lines in the opposite direction. An examination of the diagram shows that this has occurred, because the ratio lines in the upper part of the triangle show a divergence, giving a fan-like effect. In the case of the potash this divergence is already strongly noticeable, although the potash was never completely removed, as was the case with the nitrate.

In the diagram shown in figure 8 are given the ratios of the P_2O_5, NH_3, and K_2O, which exist when dihydroxystearic acid is present

in the experiment. A comparison of this with the preceding diagram shows, on the whole, a migration of the lines, so that they point to an area somewhat nearer to the nitrate end of the triangle. It will be remembered from the data already discussed that there is a tendency for the area of greatest growth under these conditions to be nearer this end.

GREEN WEIGHT OF CULTURES, CONCENTRATION, AND RATIOS OF P_2O_5, NH_3, AND K_2O IN THE VARIOUS CULTURE SOLUTIONS OF EXPERIMENT II.

In the experiment just recorded the triangle of cultures which contained dihydroxystearic acid was not grown at the same time as

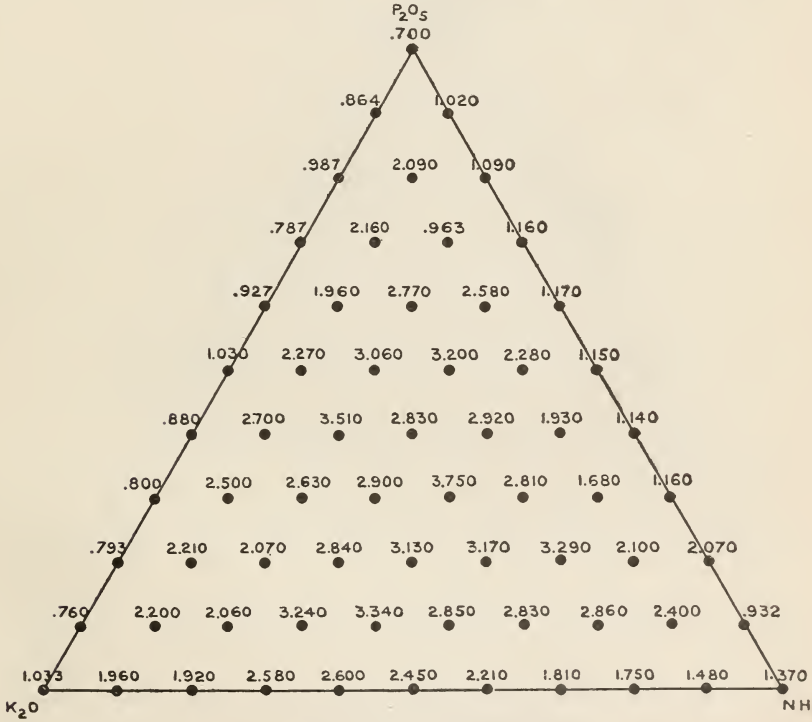

FIG. 9.—Green weight of 66 cultures with different proportions of P_2O_5, NH_3, and K_2O, without dihydroxystearic acid—Experiment II.

those in which this constituent was absent. In the following experiment, however, two triangles of 66 culture solutions each, one with dihydroxystearic acid and the other without this ingredient, were set up at the same time and the cultures maintained under equal conditions throughout. The experiment was in all other respects similar to the one described. The green weights were determined in all of the cultures, but for analysis and determining the ratios only 26 cultures were selected from each set of solutions, corresponding cultures with and without dihydroxystearic acid being analyzed. The green weights obtained in this experiment are given in figure 9

for the set without dihydroxystearic acid and in figure 10 for the set containing 50 parts per million of dihydroxystearic acid in all of the cultures. The general appearance of the plants, both as regards roots and tops, is identical with that described in the previous experiment. The interior of the triangle produced in either set a better growth than the periphery, and the effect of the dihydroxystearic acid solutions on the root system was the same as before, the roots being stunted, with swollen and darkened tips, which in some of the solutions were turned upward, giving them the appearance of hooks.

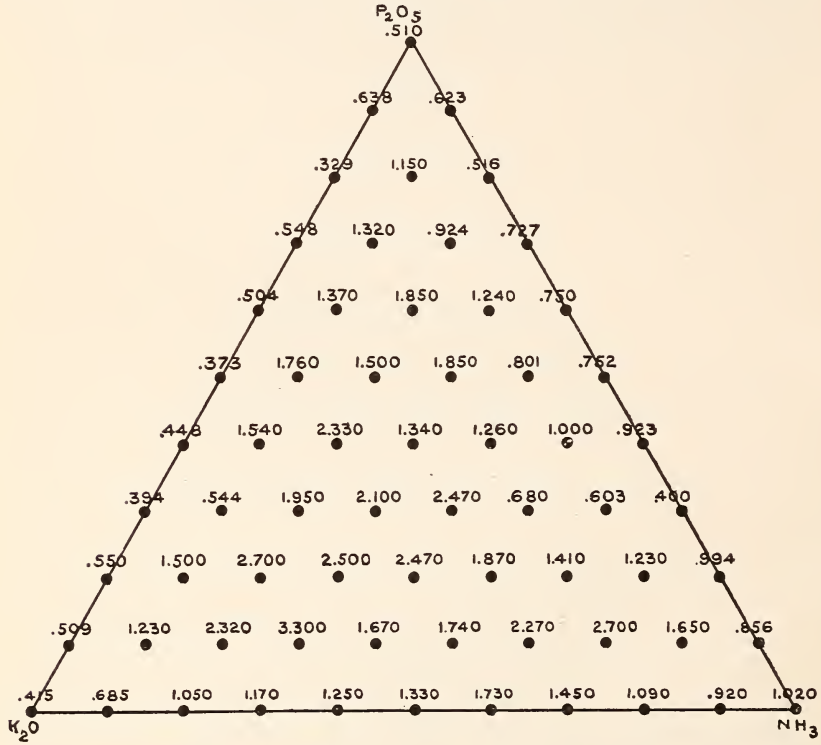

FIG. 10.—Green weight of 66 cultures with different proportions of P_2O_5, NH_3, and K_2O, with dihydroxystearic acid—Experiment II.

The total green weight of the tops of 66 cultures without the dihydroxystearic acid is 135 grams, whereas with the dihydroxystearic acid present it is only 83 grams, or a relation of 100 to 62. This relation in the growth of the two sets of plants is shown for each culture in figure 11. Attention should be called to the three apparently inconsistent high results found in the cultures near the potash end. These results are inconsistent, not only with the others in this triangle, but also with the results in the other experiments.

The concentration, at three-day intervals, of the 26 cultures selected for analysis is shown in figure 12 for the solution containing no dihydroxystearic acid and in figure 13 for those containing 50 parts per million of the substance. The general tendency appears again in this case to indicate that the solutions containing dihydroxystearic acid had the higher final concentrations, although in

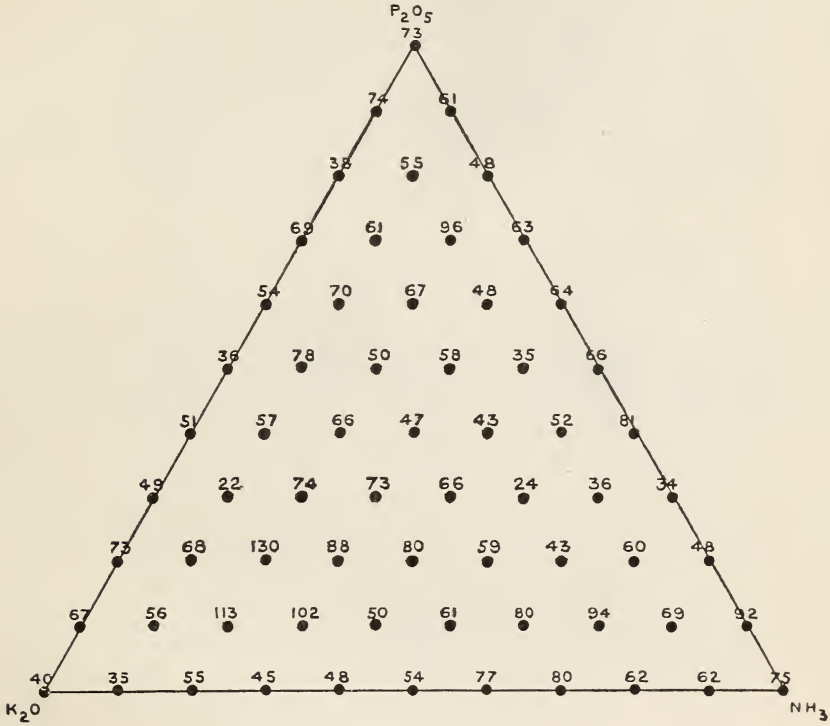

FIG. 11.—Showing the decrease in growth due to dihydroxystearic acid when the growth of the cultures without the harmful constituents equals 100—Experiment II.

the region nearer the nitrate end this is not the case. The latter effect is due entirely, as will be shown later, to the greater nitrate removal when the dihydroxystearic was present.

In Table 3 are given the ratios found in this experiment, together with the original ratios.

TABLE III.—*Showing the ratios of the average amounts of P_2O_5, NH_3, and K_2O left in 26 of the culture solutions and the ratios of the material lost from the solutions during Experiment II, together with the original ratios of these constituents.*

Culture No.	Original ratio of culture solution.			Without dihydroxystearic acid.						With dihydroxystearic acid.					
				Final ratio in the solution.			Ratio of the loss from the solution.			Final ratio in the solution.			Ratio of the loss from the solution.		
	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.
1.....	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0
5.....	80	10	10	94	0	6	54	28	18	94	0	6	46	34	20
12.....	60	10	30	90	0	10	27	21	52	81	0	19	26	26	48
13.....	60	20	20	86	3	11	29	41	30	85	3	12	26	43	31
14.....	60	30	10	70	24	6	40	43	17	84	9	7	24	62	14
16.....	50	0	50	66	0	34	19	0	81	56	0	44	14	0	86
18.....	50	20	30	86	4	10	25	31	44	75	4	21	17	41	42
21.....	50	50	0	54	46	0	36	64	0	69	31	0	17	83	0
23.....	40	10	50	70	1	29	19	16	65	55	0	45	20	23	57
25.....	40	30	30	61	24	15	22	35	43	66	10	24	19	46	35
27.....	40	50	10	45	47	8	31	56	13	52	37	11	18	75	7
31.....	30	20	50	52	9	39	16	27	57	44	4	52	14	38	48
33.....	30	40	30	40	42	18	20	36	44	48	20	32	14	57	29
34.....	30	50	20	33	54	13	25	44	31	42	37	21	16	65	19
39.....	20	20	60	27	12	61	12	29	59	30	4	66	11	35	54
41.....	20	40	40	28	43	29	13	37	50	33	27	40	11	50	39
43.....	20	60	20	21	67	12	19	49	32	32	45	23	8	76	16
44.....	20	70	10	19	73	8	23	58	19	30	58	12	6	86	8
47.....	10	10	80	13	5	82	7	16	77	13	1	86	6	23	71
49.....	10	30	60	10	19	71	10	37	53	12	10	78	9	43	48
51.....	10	50	40	8	61	31	11	41	48	17	35	48	5	61	34
52.....	10	60	30	7	78	15	13	44	43	14	49	37	6	71	23
54.....	10	80	10	6	86	8	17	68	15	15	74	11	5	86	9
56.....	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100
61.....	0	50	50	0	53	47	0	43	57	0	41	59	0	68	32
66.....	0	100	0	0	100	0	0	100	0	0	100	0	0	100	0

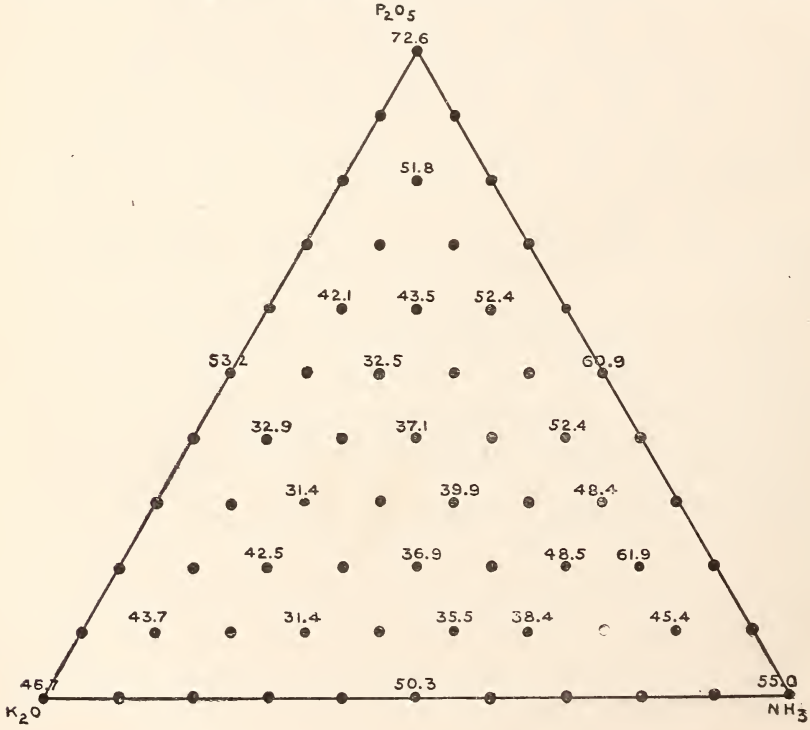

FIG. 12.—Showing the average concentration in parts per million of $P_2O_5 + NH_3 + K_2O$ in the solution after growth of wheat plants, without dihydroxystearic acid—Experiment II.

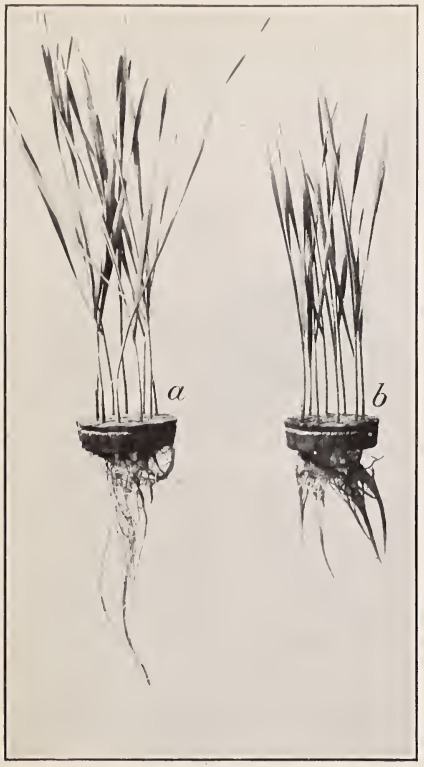

FIG. 1.

Wheat plants growing in culture solutions containing a fertilizer mixture composed of phosphate 60 per cent, nitrogen 20 per cent, potash 20 per cent: *a*, without dihydroxystearic acid; *b*, with dihydroxystearic acid.

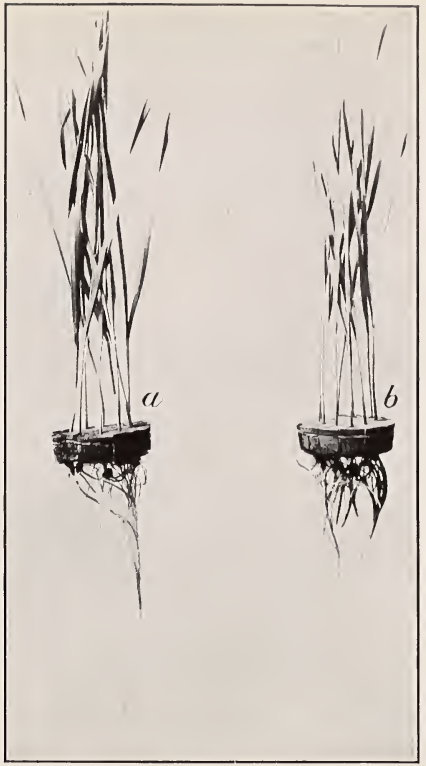

FIG. 2.

Wheat plants growing in culture solutions containing a fertilizer mixture composed of phosphate 20 per cent, nitrogen 20 per cent, potash 60 per cent: *a*, without dihydroxystearic acid; *b*, with dihydroxystearic acid.

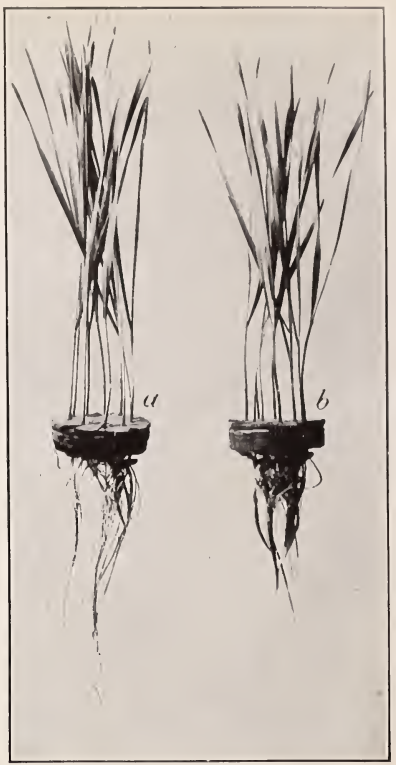

FIG. 3.

Wheat plants growing in culture solutions containing a fertilizer mixture composed of phosphate 20 per cent, nitrogen 60 per cent, potash 20 per cent: *a*, without dihydroxystearic acid; *b*, with dihydroxystearic acid.

In figures 14 and 15 are shown the changes in average ratios of the solution during the experiment. The results for the solutions without dihydroxystearic acid are given in figure 14 and for the solutions with dihydroxystearic acid in figure 15. In the first case the lines appear to converge toward an area slightly nearer to the potassium angle than in the preceding experiment, although in the solutions containing dihydroxystearic acid this area is again displaced toward the nitrate angle.

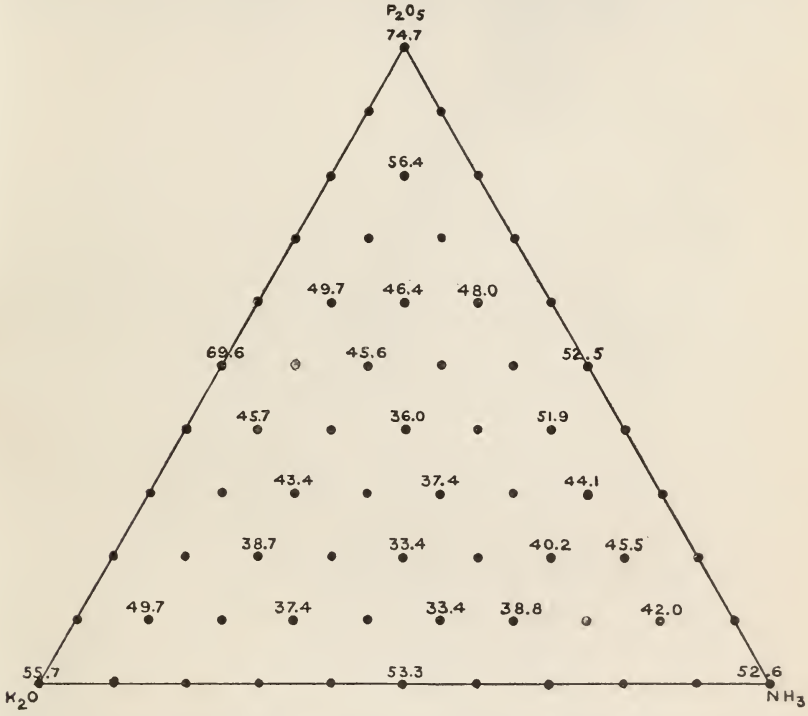

FIG. 13.—Showing the average concentration of the solution, in parts per million of $P_2O_5 + NH_3 + K_2O$, after the growth of wheat plants, with dihydroxystearic acid—Experiment II.

GREEN WEIGHT OF CULTURES, CONCENTRATION, AND RATIOS OF P_2O_5, NH_3, AND K_2O IN THE VARIOUS CULTURE SOLUTIONS OF EXPERIMENT III.

A third experiment using 66 cultures, with and without dihydroxystearic acid, was set up on June 8. These were in all respects similar to the preceding sets, except that the duration of the experiment was shorter, owing to a limited supply of dihydroxystearic acid which was exhausted with the fourth change of the solutions, or after a period of only twelve days. The green weights of the cultures are given in figures 16 and 17. The total growth of the 66 cultures without the dihydroxystearic acid was 137 grams, while the growth with

the dihydroxystearic acid present was only 88 grams, or a relation of 100 to 64. Here again the higher region of growth is found in the interior of the triangle near the center but, as in the other cases, below the center and, in the case of dihydroxystearic acid, displaced toward the nitrate angle. The relation of the growths in solutions with and without dihydroxystearic acid is given in figure 18 for each of the culture ratios.

As in the preceding experiment only 26 cultures were selected for analysis. The final concentration in the cultures with and without

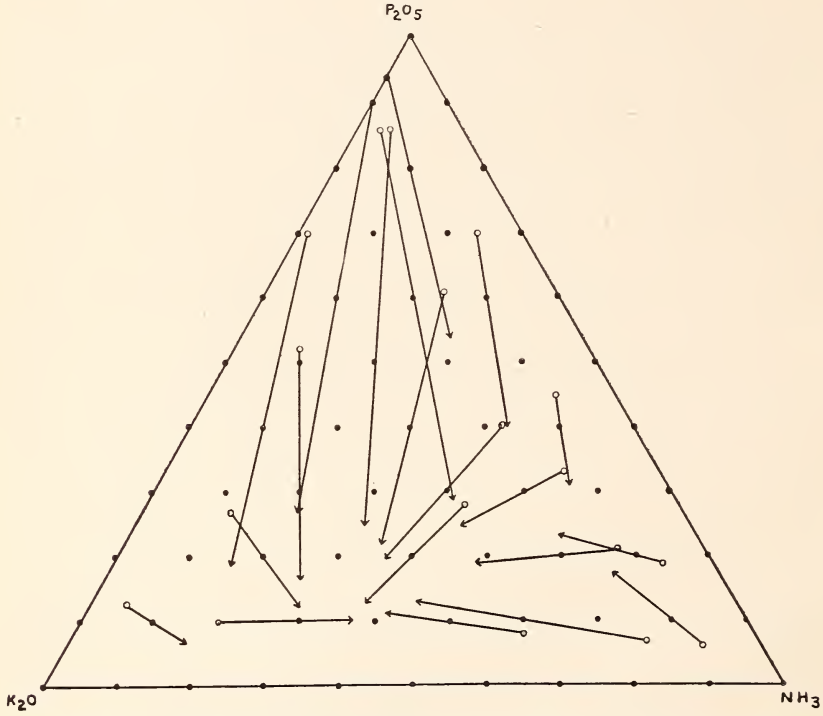

FIG. 14.—Showing the ratios of P_2O_5, NH_3, and K_2O in the original solutions, those in the solutions after growth, and those of the loss from the culture solutions, without dihydroxystearic acid—Experiment II.

dihydroxystearic acid are given in figures 19 and 20. Here again the general tendency is for the residual concentration of the solutions containing dihydroxystearic acid to be higher than in case of the solution which did not contain this body, although as in the preceding experiment this is not always so in the nitrate angle of the triangle, for the reason mentioned in connection with the preceding experiment.

In Table IV are given the ratios found by analysis in this experiment.

TABLE IV.—*Showing the ratios of the average amounts of P_2O_5, NH_3, and K_2O left in 26 of the culture solutions and the ratios of the material lost from the solutions during Experiment III, together with the original ratios of these constituents.*

Culture No.	Original ratio of culture solution.			Without dihydroxystearic acid.						With dihydroxystearic acid.					
				Final ratio in the solution.			Ratio of the loss from the solution.			Final ratio in the solution.			Ratio of the loss from the solution.		
	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.
1	100	0	0	100	0	0	100	0	0	100	0	0	100	0	0
5	80	10	10	97	0	3	43	31	26	95	0	5	43	35	22
12	60	10	30	96	0	4	17	22	61	83	0	17	16	29	55
13	60	20	20	90	2	8	21	43	36	88	3	9	17	46	37
14	60	30	10	74	23	3	26	46	28	77	15	8	20	62	18
16	50	0	50	65	0	35	10	0	90	57	0	43	11	0	89
18	50	20	30	93	3	4	17	33	50	78	6	16	10	40	50
21	50	50	0	66	34	0	15	85	0	70	30	0	7	93	0
23	40	10	50	79	0	21	15	16	69	59	0	41	10	25	65
25	40	30	30	74	21	5	17	36	47	64	15	21	11	48	41
27	40	50	10	52	45	3	22	58	20	55	37	8	12	74	14
31	30	20	50	65	5	30	12	28	60	46	8	46	10	34	56
33	30	40	30	49	43	8	14	37	49	46	30	24	10	51	39
34	30	50	20	41	52	7	16	47	37	47	39	14	8	64	28
39	20	20	60	41	5	54	10	27	63	34	6	60	8	33	59
41	20	40	40	38	46	16	10	36	54	35	26	39	6	53	41
43	20	60	20	28	68	4	11	51	38	36	51	13	6	68	26
44	20	70	10	23	73	4	14	63	23	32	60	8	6	82	12
47	10	10	80	15	6	79	5	15	80	15	2	83	3	23	74
49	10	30	60	14	34	52	7	27	66	16	15	69	5	43	52
51	10	50	40	15	71	14	8	39	53	16	51	33	5	50	45
52	10	60	30	10	83	7	10	42	48	16	60	24	2	59	39
54	10	80	10	9	87	4	10	72	18	14	80	6	2	80	18
56	0	0	100	0	0	100	0	0	100	0	0	100	0	0	100
61	0	50	50	0	65	35	0	41	59	0	53	47	0	47	53
66	0	100	0	0	100	0	0	100	0	0	100	0	0	100	0

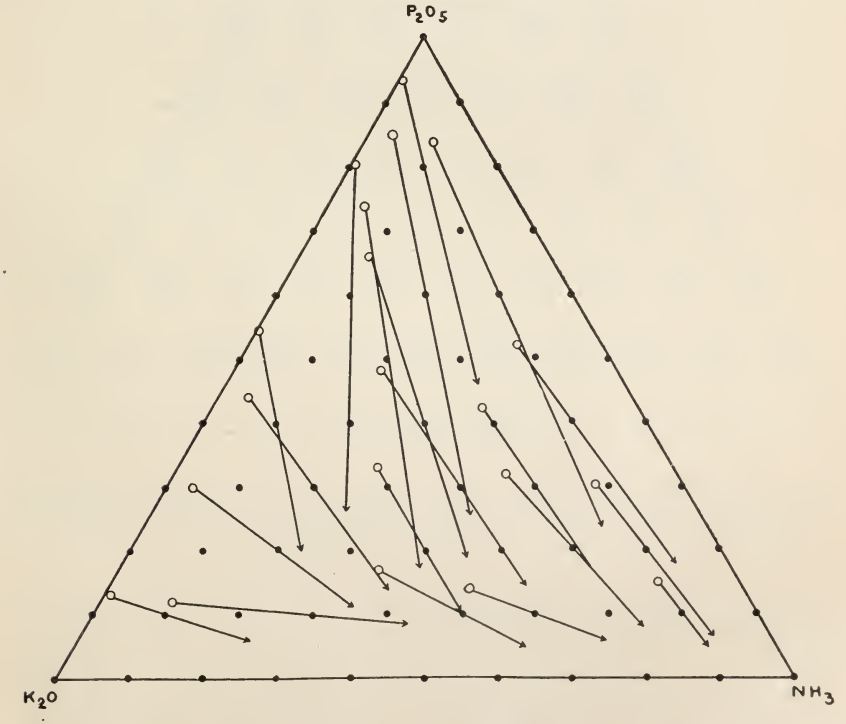

FIG. 15.—Showing the ratios of P_2O_5, NH_3, and K_2O in the original solutions, those in the solutions after growth, and those of the loss from the culture solutions, with dihydroxystearic acid—Experiment II.

The ratios of the constituents P_2O_5, NH_3, and K_2O, in the original solutions, those of the materials removed during plant growth, and those of the materials remaining in the solutions, are indicated in figures 21 and 22. The diagrams show in general the same trend in the results as is exhibited in the diagram for the preceding experiment, except that when the dihydroxystearic acid is present, the radiation from any special area is not so marked, and the displacement of this area toward the nitrate angle, as was the case in the two previous experiments, is not so apparent, although a shifting of nearly all of the lines in that direction is noticeable.

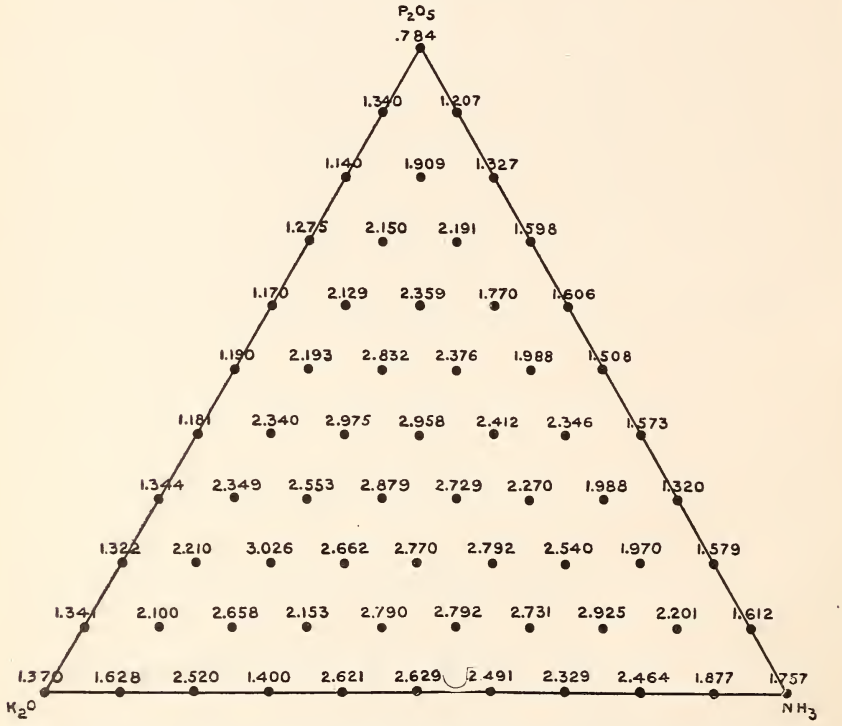

FIG. 16.—Green weight of 66 cultures with different proportions of P_2O_5, NH_3, and K_2O, without dihydroxystearic acid—Experiment III.

THE COMPARATIVE EFFECT PRODUCED ON THE DIHYDROXYSTEARIC ACID CULTURE SOLUTIONS BY THE FERTILIZER MIXTURES COMPOSED MAINLY OF P_2O_5, NH_3, AND K_2O, RESPECTIVELY.

In the experiments already presented, there was noticed a more general tendency toward normal development of the plants in the presence of the dihydroxystearic acid when the culture solutions contained all three of the nutrient substances. It was further apparent that there seemed to be a general tendency for more normal develop-

ment in a region nearer to the nitrate end. In order to trace out this matter, a comparison of the three experiments has been made and will be presented at this time. For this purpose the results obtained in all the cultures represented by the triangle marked by the points 1–16–21 of the diagram, figure 1; all the cultures marked by the triangle 21–61–66, and all cultures marked by the triangle 16–61–56, were considered as groups. In this way the solutions which contained in all cases 50 and more per cent of P_2O_5 are contained in the first group; all those which contained 50 per cent or more of NH_3, in the second group; and those with 50 per cent or more of K_2O,

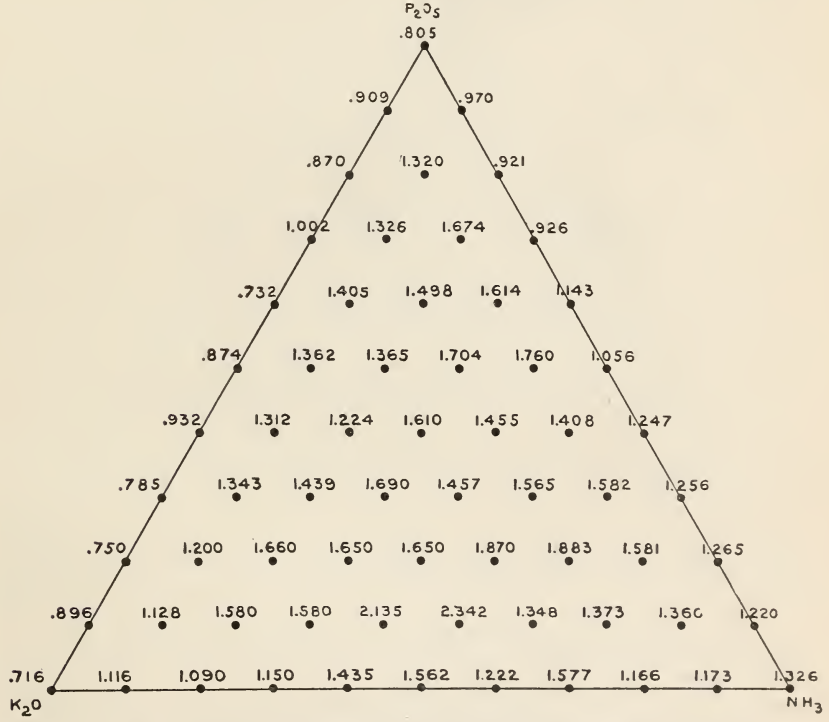

FIG. 17.—Green weight of 66 cultures with different proportions of P_2O_5, NH_3, and K_2O, with dihydroxystearic acid—Experiment III.

in the third group. By grouping the cultures thus an average result is obtained with the mainly phosphatic, mainly nitrogenous, and mainly potassic fertilizers.

A comparison of the average green weight in each of these groups of triangles was made with the weights in the corresponding groups in the cultures where dihydroxystearic acid was present. Assuming the weights in the groups where no acid was present to be 100, the weights in the corresponding groups where the dihydroxystearic acid was present are given in Table V.

TABLE V.—*Showing the average relative growth made in the groups of solutions with dihydroxystearic acid and containing fertilizer salts having the composition of 50 to 100 per cent of any one of the components P_2O_5, NH_3 and K_2O, the growth in the corresponding groups without the acid being taken as 100.*

Experiment.	Relative green weight in group having—		
	P_2O_5, 50–100 per cent.	NH_3, 50–100 per cent.	K_2O, 50–100 per cent.
1	49	67	43
2	60	62	62
3	71	68	61

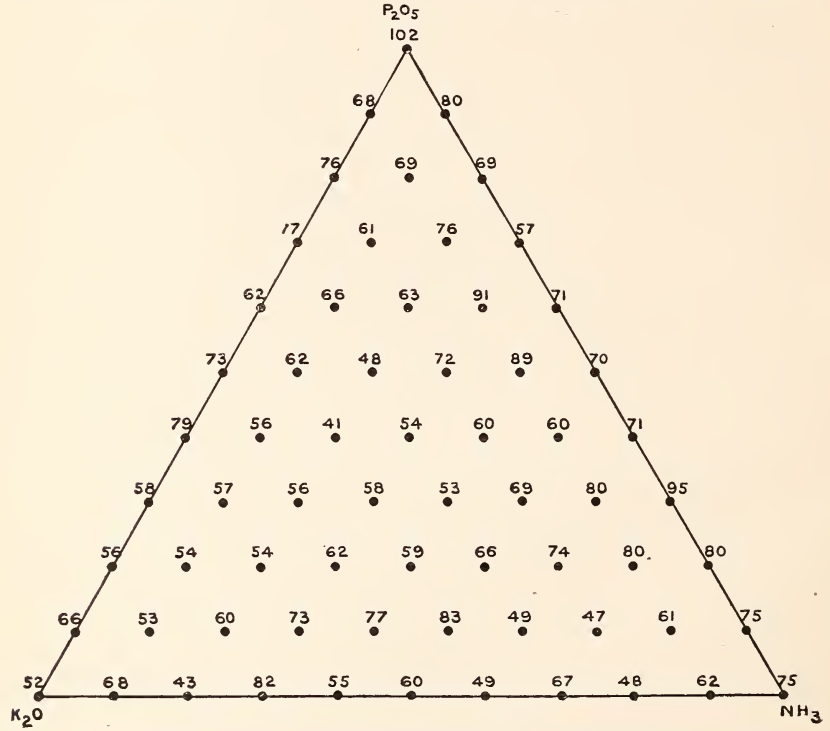

FIG. 18.—Showing the decrease in growth due to dihydroxystearic acid when the growth of the cultures without the harmful constituent equals 100—Experiment III.

In the first column is given the number of the experiment; in the second column the average relative green weight obtained in the solutions having mainly phosphatic fertilizers; in the third column the same result for the culture solutions with mainly nitrogenous fertilizers; and in the fourth column the results obtained when mainly potassic fertilizers were present. The results again indicate, as was pointed out in discussing each experiment separately, that the mainly nitrogenous fertilizers enabled the plants to make a more normal growth than on the whole do the other fertilizers, although, with the quantities of salts and harmful substance used in these experiments,

the plants were by no means able to overcome the harmful effect entirely, if, indeed, this is possible.

This general relationship is more strongly shown when the decreases in the concentrations of the solutions in these various groups are considered. The average decrease, in solutions with and without dihydroxystearic acid, for each group in each experiment, is shown in Table VI.

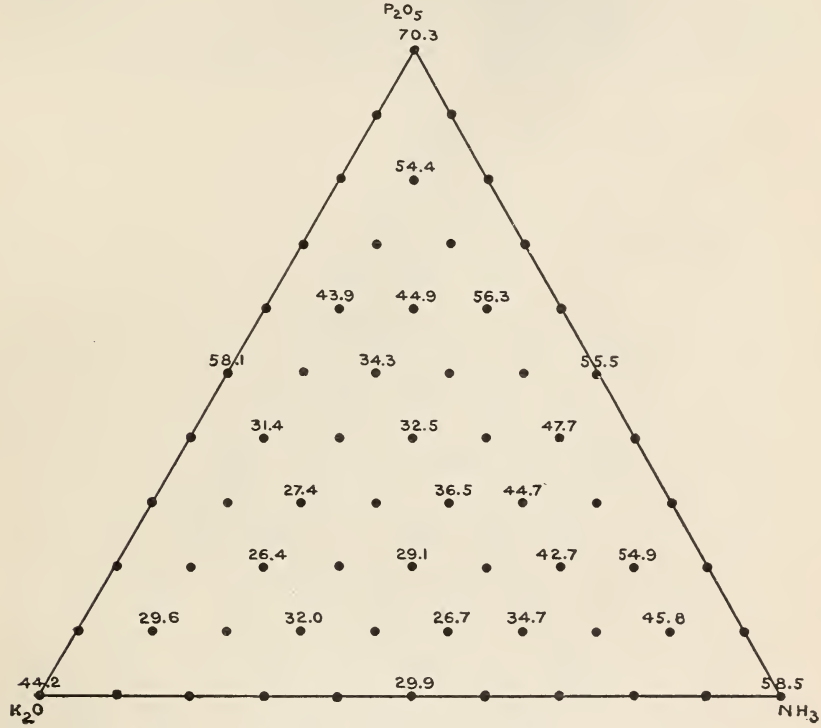

FIG. 19.—Showing the average concentration of the solution, in parts per million of $P_2O_5 + NH_3 + K_2O$, after growth of wheat plants, without dihydroxystearic acid—Experiment III.

TABLE VI.—*The average decreases in the concentration of total fertilizer constituents in the groups of culture solutions with 50 to 100 per cent of any one of the components P_2O_5, NH_3, and K_2O, without and with dihydroxystearic acid.*

[Original concentration, 80 parts per million.]

Experiment No.	Decrease occurring in solutions with—								
	P_2O_5, 50–100 per cent.			NH_3, 50–100 per cent.			K_2O, 50–100 per cent.		
	Without dihydroxystearic acid. (Normal decrease.)	With dihydroxystearic acid.		Without dihydroxystearic acid. (Normal decrease.)	With dihydroxystearic acid.		Without dihydroxystearic acid. (Normal decrease.)	With dihydroxystearic acid.	
	Parts per million.	*Parts per million.*	*P. ct. of normal.*	*Parts per million.*	*Parts per million.*	*P. ct. of normal.*	*Parts per million.*	*Parts per million.*	*P. ct. of normal.*
1	27.8	17.6	63	35.4	24.0	68	34.0	13.9	41
2	28.9	24.6	85	30.3	34.6	114	38.5	30.8	80
3	27.8	23.8	85	35.9	32.0	89	45.0	31.0	69

The third column under each fertilizer group gives the percentage relation between the decreases, the decrease in concentration when dihydroxystearic acid is absent being considered as the normal for comparison and equal to 100. A comparison of these relative effects shows that the mainly nitrogenous fertilizers give the highest results. In other words, the decrease with the nitrogenous fertilizers was more nearly like that observed under the normal conditions where dihydroxystearic acid was absent. This result can only be interpreted to mean that the mainly nitrogenous fertilizers decreased the inhibitive

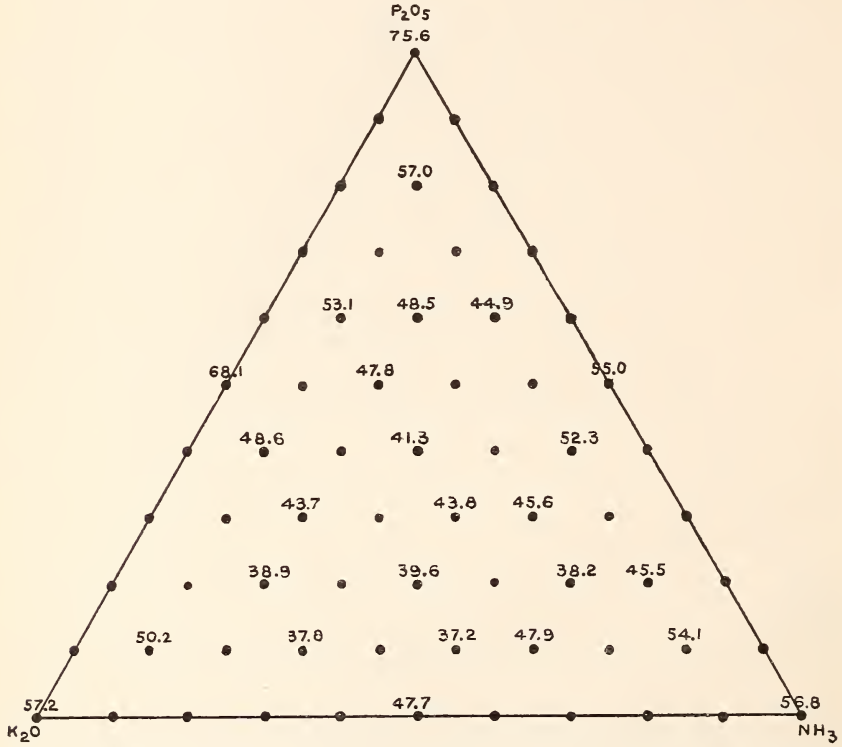

FIG. 20.—Showing the average concentration of the solution, in parts per million of $P_2O_5 + NH_3 + K_2O$, after growth of wheat plants, with dihydroxystearic acid—Experiment III.

effect of the dihydroxystearic acid, although it does not show whether this is a direct or an indirect effect; i. e., whether there is an actual decrease of this inhibitive material or whether there is mainly the ability of the plant to withstand the attacks under these conditions. Attention has already been called to the fact that this substance when in soils is most easily destroyed by processes which promote oxidation; and it should be borne in mind that the nitrogenous fertilizers are mainly ones which promote the most active root oxidation by the plants themselves. A study of the oxidation of roots in these experi-

ments showed that the dihydroxystearic acid interfered greatly with oxidation, and that this action was overcome to some slight extent in the center of the triangle but nearer to the nitrate end, thus showing perhaps that there is some correlation in these functions.

THE RESULTS OF THE EXPERIMENTS CONSIDERED BY PERIODS.

In considering the results thus far the average of the various periods has been taken as the basis for discussion. The very earliest periods, however, when compared with the later periods, do show some differ-

FIG. 21.—Showing the ratios of P_2O_5, NH_3, and K_2O in the original solutions, those in the solutions after growth, and those of the loss from the culture solutions, without dihydroxystearic acid—Experiment III.

ences in the ratio in which the three elements are removed, as has already been pointed out.

Mention has already been made of the fact that the ratios removed from the solutions along the lower phosphate line, namely, those having 8 parts per million of that fertilizer ingredient, had a tendency to cause the ratio lines to turn from a point below this line to points above the line. This general behavior of the cultures is very well shown by the diagrams for the first, second, and third periods, of Experiment I in which solutions containing no dihydroxystearic acid were used. The first diagram (fig. 23) shows the arrow points

of the 10 per cent phosphate mixtures to lie below this line. The second diagram (fig. 24) shows some of the points above and some still below the line. In the third diagram (fig. 25) all but one lie above the line and some of the 20 per cent phosphate line are also noticed to have turned so far as to take a position even slightly above this line. There is, moreover, a general tendency for all of the points to lie somewhat higher for the other solutions, thus showing that this influence is probably common to all, though seen most strikingly in those containing smaller amounts, where an actual reversal takes place. This general result may be interpreted to mean that the

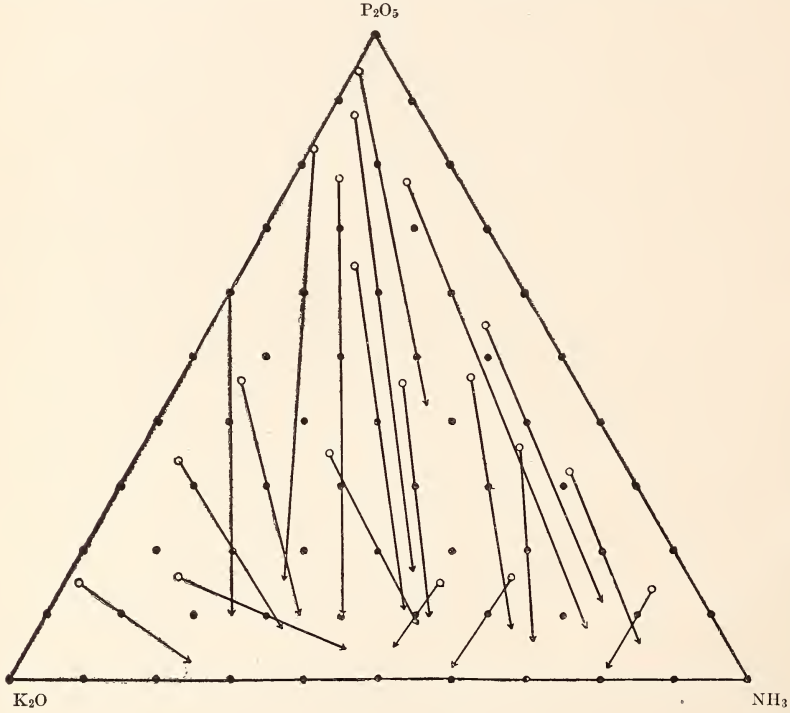

FIG. 22.—Showing the ratios of P_2O_5, NH_3, and K_2O in the original solutions, those in the solutions after growth, and those of the loss from the culture solutions, with dihydroxystearic acid—Experiment III.

relative amount of phosphate removed in the early stages of the seedlings is not so great as it is subsequently, and the phenomenon can probably be correlated with the fact that in experiments where distilled water is used rather than these culture solutions, phosphate is excreted by the germinating seed and can be detected in the water in which germinating seeds or young seedlings bathe. Although the seedlings when used in these experiments had passed in the main through this stage, the results show that the power to remove phosphate was small, probably due to the fact that the process of the

phosphate absorption had not fully replaced the opposite function existing during germination and early growth.

The potassium is also different from that in the later periods, although this is not so striking in the diagram as in the case of the phosphate. The average ratio of the absorbed material during these first three periods for all the cultures is 19 for phosphate, 39 for nitrate, and 42 for potassium, whereas the average for the five succeeding periods is 21 for phosphate, 44 for nitrate, and 35 for potash, thus showing that there is a tendency for a relatively greater potash and a

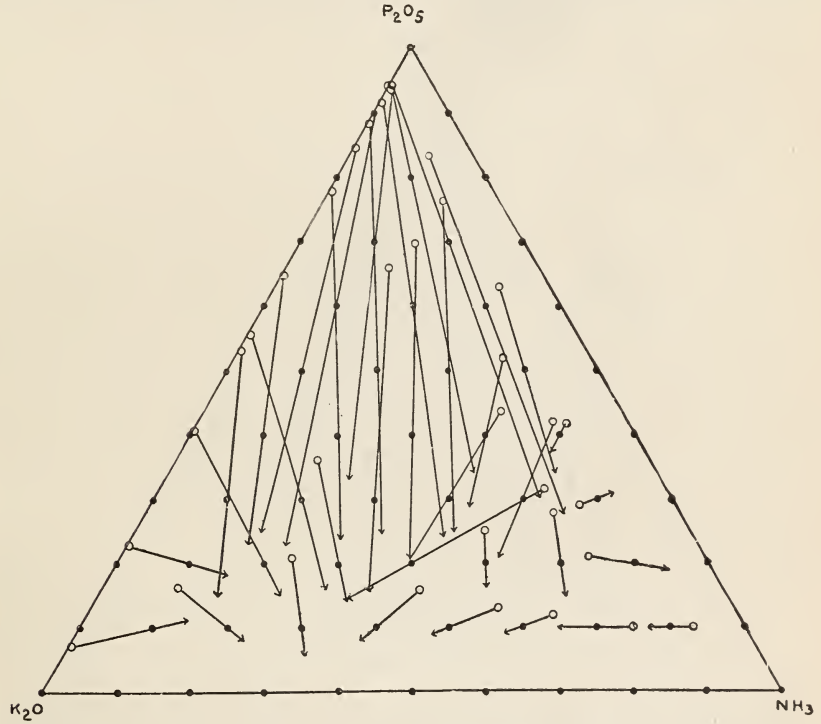

FIG. 23.—Showing the ratios of P_2O_5, NH_3, and K_2O in the original solutions, those in the solutions after growth, and those of the loss of the constituents from the solutions during the first period of Experiment I, without dihydroxystearic acid.

relatively lesser phosphate absorption to take place during the earlier periods. As far as the influence of these fertilizer elements on growth is concerned, however, it is to be noticed that the nitrate has the greatest effect, as is shown by the fact that the difference between the no-nitrogen line and the line having 8 parts per million is very great in the case of the nitrate, less in the case of the potash, and least in the case of the phosphate.

Beyond the third period the results in the experiment were about the same, so far as ratios of the ingredients are concerned, as can be

seen from the diagram already given for the average result covering the entire eight periods in Experiment I. These same general tendencies existed in the other experiments.

When dihydroxystearic acid is present the results are slightly different, there being always in that case a tendency for the ratios of the materials removed from the solution to fall nearer to the nitrogen angle of the diagram than they do in the case of cultures where this substance is absent. This tendency is, in some of the experiments, marked from the very first, as is shown by the diagram given in figure 26 for the first period in Experiment I. Moreover, the

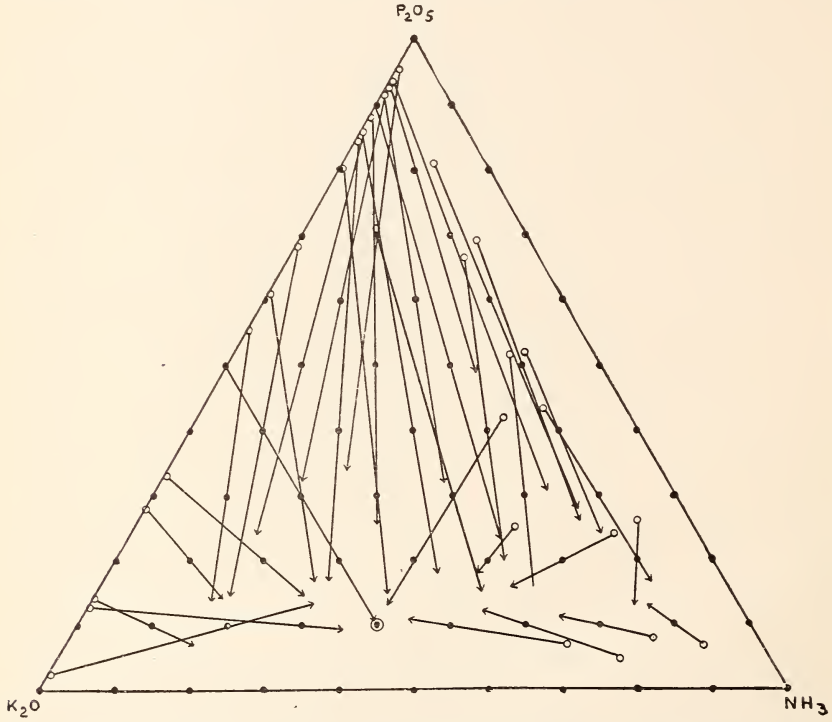

FIG. 24.—Showing the ratios of P_2O_5, NH_3, and K_2O in the original solutions, those in the solutions after growth, and those of the loss of the constituents from the solutions during the second period of Experiment I, without dihydroxystearic acid.

points of, for instance, the 10 per cent mixtures of P_2O_5, lie very low, and this tendency to lie lower than in the cultures which contained no dihydroxystearic acid is found throughout the experiment, though it is not equally marked in all periods. The average effect has already been given in the diagram, figure 8. The strong tendency, which is shown when this substance is present for a proportionately, and sometimes even absolutely, greater decrease in the nitrogen of the solutions, is strikingly shown in this first period, figure 26. This varies somewhat from period to period, thus, for instance, in the

fourth period shown in figure 27, the ratio change is fairly normal, though the usual tendency is seen again in the seventh period, a diagram of which is presented in figure 28. The two sets of diagrams for the several periods illustrate rather well the general tendencies brought out by an examination of the analytical data. As a rule, beyond the second or perhaps the third period the diagrammatic representation of the result is on the whole uniform, but is influenced undoubtedly by the conditions of growth during any period; in other words, by weather and other conditions which is shown perhaps quickest in the nitrate removal from the cultures.

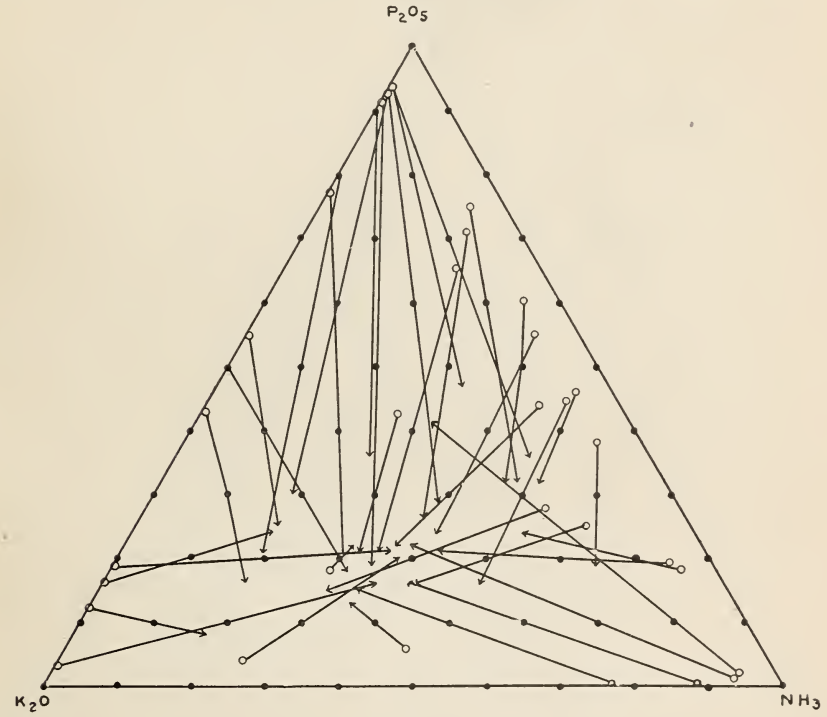

FIG. 25.—Showing the ratios of P_2O_5, NH_3, and K_2O in the original solutions, those in the solutions after growth, and those of the loss of the constituents from the solutions during the third period of Experiment I, without dihydroxystearic acid.

Some remarks should here be made concerning the possible influence of bacteria. In the course of these experiments bacteria and other microorganisms were excluded as far as possible, but no special effort was made to maintain absolutely sterile conditions, inasmuch as this would have been a practical impossibility in an experiment on so large a scale. Moreover, it may even appear questionable whether absolute sterility would be desirable. The bottles were sterilized before being used in making culture solutions for the various changes, the pans and other apparatus used in germinating

the seed were sterilized from time to time, and corks used for the cultures were always clean and sterilized before use. Although all of these precautions were taken, it was of course not possible to exclude some microorganisms in such work, as the solutions were exposed from time to time to the air. There was in no case any excessive microorganic life noticeable. While bacteria and other microorganisms were present in the solutions to a slight and, under the conditions, unavoidable extent, it can hardly be said that their influence could have been large; that is, such influence as they had

FIG. 26.—Showing the ratios of P_2O_5, NH_3, and K_2O in the original solutions, those in the solutions after growth, and those of the loss of the constituents from the solutions during the first period of Experiment I, with dihydroxystearic acid.

was probably so slight as to be negligible so far as the general and larger tendencies which are shown in this paper to exist are concerned.

Controls which were set up without having plants grown in them were found not to have changed their concentration nor proportions of the constituents. Moreover, the various experiments support each other in their general tendencies. Most striking perhaps is the fact that more nitrogen was lost in the solutions containing the dihydroxystearic acid and that this relatively greater loss in comparison with the other fertilizer elements was noticeable from the

very first, being strongly marked in the first period, as has just been shown, and that later this tendency was lost or diminished, to appear again at a still later period. In other words, if the greater disappearance of nitrates in this case were to be ascribed to bacterial activity, this should have shown itself all the more prominently as the age of the cultures increased, especially under the weakened conditions of the roots in the dihydroxystearic-acid cultures. Such changes as were noticed might be ascribed to changes in the climatic conditions from period to period, thus still further affecting the plant's metabolism. This is very nicely illustrated in a series of

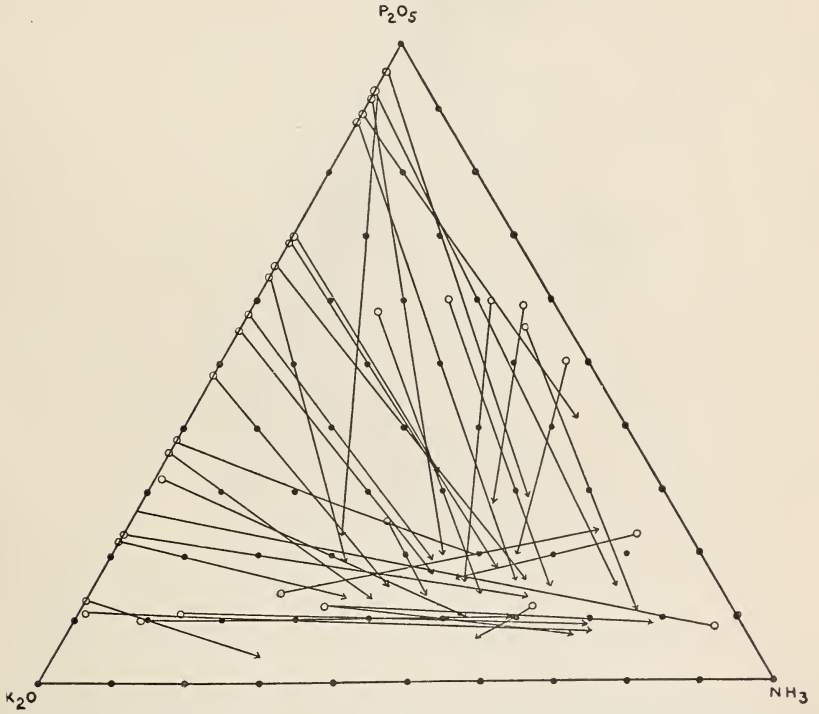

FIG. 27.—Showing the ratios of P_2O_5, NH_3, and K_2O in the original solutions, those in the solutions after growth, and those of the loss of the constituents from the solutions during the fourth period of Experiment I, with dihydroxystearic acid.

preliminary experiments in which the solutions were changed every day instead of every three days as was finally done. The diagram presented in figure 29 gives the result obtained on a clear day in this experiment, showing the relatively greater amount of nitrogen absorbed under these conditions. Figure 30 shows the result obtained on the following day which was cloudy and rainy. Relatively less nitrogen was absorbed on the cloudy and rainy day, as shown in this diagram. It would be obviously unfair to conclude that under such conditions bacterial activities had been greater on the sunny

day than on the following rainy day, expecially as this result is in harmony with all observations on the removal of nitrate from solutions by plants. The processes of nitrogen utilization within the plant are known to be greater under conditions of better illumination. It is therefore fair to assume that this same general tendency held in all the other cultures and that whatever effect the bacteria may have had, it was slight in comparison to the activities of the plant itself under the conditions of this experiment. There should also be mentioned the fact that, with the greater decrease in the amount

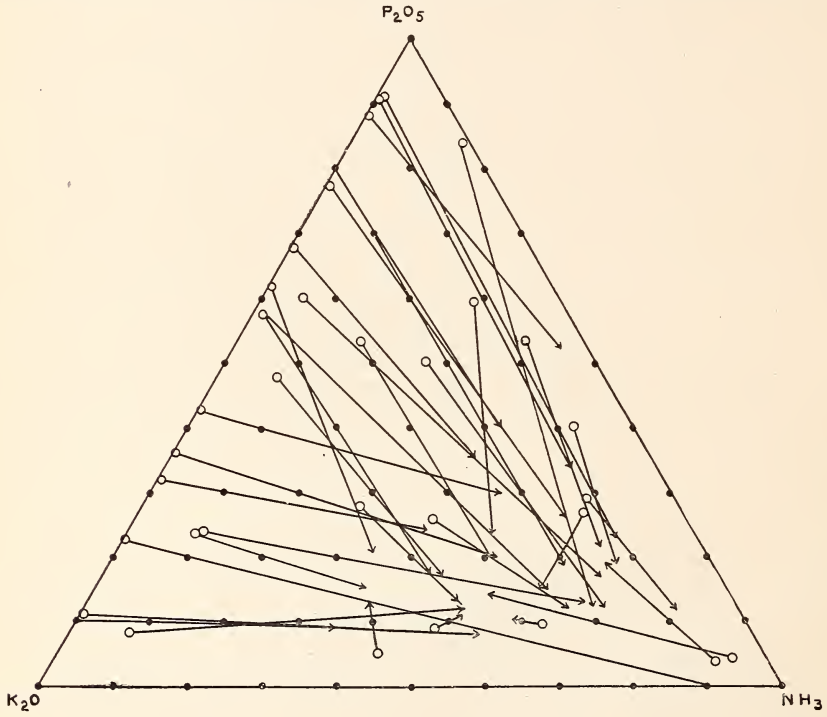

FIG. 28.—Showing the ratios of P_2O_5, NH_3, and K_2O in the original solutions, those in the solutions after growth, and those of the loss of the constituents from the solutions during the seventh period of Experiment I, with dihydroxystearic acid.

of nitrate noticed in certain regions of the dihydroxystearic acid culture triangle, there was always associated a relatively greater growth which could hardly have been the case if in these solutions, in which the greater growth occurred, there had also been the greater loss of nitrogen by bacterial activity; or, if so, it would mean that the bacterial products were distinctly beneficial rather than otherwise. In other words, the ratio of the constituents removed fall in the same region of the triangle in which are found the cultures in which the greatest growth occurs, and the region of greater growth is associated

with the greater removal of nitrates, which would hardly be the case if the bacterial activities had played a prominent part in the observed results other than as above suggested.

ANALYTICAL METHODS AND DETAILED RESULTS.

After changing the solutions at the end of the third day, these, as already stated, were brought to the laboratory for analysis, and the concentration of nitrate, phosphate, and potassium was determined. The quantities involved are necessarily small and colori-

FIG. 29.—Showing the ratios of P_2O_5, NH_3, and K_2O in the original solutions, those in the solutions after growth, and those of the loss of the constituents from the solutions, for a clear day. (In this experiment the solutions were changed and analyzed daily.)

metric methods, which had been devised for the determination of small amounts of these substances, in aqueous extracts from soils, were used with very satisfactory results. With these methods it was possible to detect slight differences in concentration, differences so small that to have determined them accurately with any of the present gravimetric or volumetric methods would have been impossible. The colorimeter used in this work is that described elsewhere.[a] The

[a] Schreiner and Failyer, Bul. 31, p. 25, Bureau of Soils, U. S. Dept. Agr., 1906. Schreiner, Jour. Am. Chem. Soc., 27, 1192 (1905).

methods for the nitrate and the phosphate determinations enabled the completion of the analysis on the day the solutions were changed, but the procedure for the potash determination, which is somewhat more tedious, required several days.

DETERMINATION OF NITRATE IN THE SOLUTIONS.

The culture solutions were made up to the original volume of 250 c. c. with distilled water.

For the nitrate determination 10 c. c. of each of the solutions was withdrawn and transferred to a Berlin porcelain evaporating dish

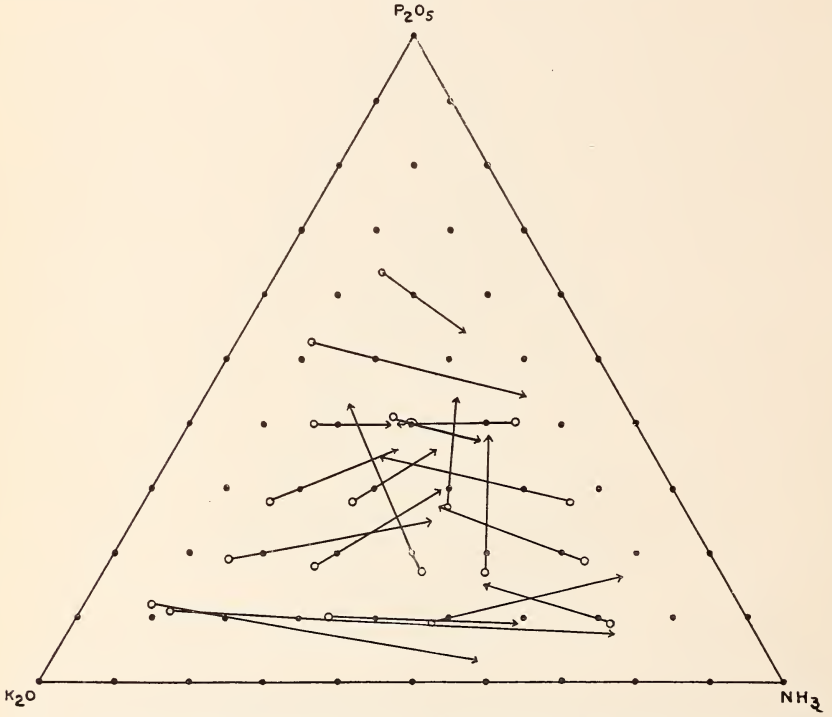

FIG. 30.—Showing the ratios of P_2O_5, NH_3, and K_2O in the original solutions, those in the solutions after growth, and those of the loss of the constituents from the solutions, for a cloudy and rainy day immediately succeeding the clear day shown in figure 29.

bearing a number corresponding to that of the culture. The solutions were evaporated to dryness on a steam bath, being removed immediately when dry. After cooling, 1 c. c. of the phenoldisulphonic acid reagent was added to each dish and well stirred with the rounded end of a glass rod, allowing the reagent to act about ten minutes. The acid was then diluted with water and made alkaline with ammonium hydroxide. The yellow solution was then diluted to a convenient volume comparable to the intensity of the standard colorimetric solution, prepared at the same time, and was then compared with the

latter in the colorimeter. The results are stated in terms of NH_3 as this was the fertilizer designation used throughout the work. The details of this method are given in Bulletin 31, page 39.

DETERMINATION OF PHOSPHATE IN THE SOLUTIONS.

The phosphate in the solutions was determined by the method described on page 46 of Bulletin 31, Bureau of Soils. In this method both the phosphate and silica are determined when the latter is present. In these experiments, however, the method was greatly simplified inasmuch as repeated tests showed the almost total absence of silica in the solutions. As already mentioned, the glass containers used for these solutions were composed of very hard flint glass. In this case, therefore, the silica being zero, the two results obtained by this procedure were duplicates. In determining the phosphate, portions of the solution were measured out in duplicate, 50 c. c. in those cases where the weaker phosphate solutions were concerned and only 25 c. c. in the case of the stronger solutions, the latter being, however, made up to 50 c. c. before adding the necessary reagents. This was done to insure a sufficient amount of reagents to develop the full color. To one portion were then added 5 c. c. of the nitric acid reagent and 4 c. c. of the ammonium molybdate reagent and the color read after twenty minutes in the colorimeter in comparison with a standard solution prepared at the same time. To the other portion only the ammonium molybdate reagent was added, allowed to stand one hour, and then the nitric acid solution added and after twenty minutes the color compared with the standard as in the previous case. As already stated, the intensity of the color in these two solutions was the same, thus showing the absence of silica. If silica had been present, the intensity of the color developed under the two conditions would have been different and the amount of phosphate and silica, respectively, could have been calculated by means of the formula given in the original papers.

DETERMINATION OF POTASSIUM IN THE SOLUTIONS.

The potassium was determined by the colorimetric method of Cameron and Failyer[a] and given in detail in Bulletin 31, page 31. Both porcelain and electroquartz dishes were used in the investigation without, however, noticing any special advantage of the one over the other for this purpose. Of the stronger solutions 10 c. c. were used, i. e., those originally containing from 64 to 80 parts per million, 25 c. c. of those containing from 32 to 64 parts per million, and 50 c. c. of the weaker solutions. Only half of the solutions were run through at a time, as this was found to be the most expeditious

[a] Jour. Amer. Chem. Soc., 25, 1063 (1903).

way of handling this large number of analyses. All the solutions were measured off on the day on which the cultures were changed, 0.5 c. c. of dilute sulphuric acid added, and evaporated to dryness, the excess of sulphuric acid being driven off by heating over a naked flame. The last operation destroys any organic matter that may be present. The measured samples were then allowed to stand in covered receptacles until the following day when half of them were put through the remaining part of the operation, as mentioned above, the other half being started on the third day. The rest of the process consisted in reheating the dish the next morning to drive off any absorbed ammonium salts and then adding to the cooled dish a few drops of hydrochloric acid and several drops of platinum chloride solution to slight excess. The residue was well worked with the rounded end of a short stirring rod and evaporated on a steam bath almost to dryness. The residue was then washed several times with alcohol and the washings poured through a carefully purified asbestos filter contained in a Gooch crucible. As much as possible of the residue was allowed to remain in the porcelain dish. After drying, the precipitate contained in the dish and in the Gooch crucible was dissolved in hot water and after cooling, one drop of hydrochloric acid and 0.5 c. c. of potassium iodide solution was added. A standard colorimetric solution of potassium platinic chloride is prepared at the same time and the solutions allowed to stand over night for a full development of the color. The next morning they are read in the colorimeter. The second half of the solutions are then analyzed in the same manner. In this way it is possible for one man to analyze all the cultures every three days.

AMOUNTS OF P_2O_5, NH_3, AND K_2O FOUND IN THE VARIOUS CULTURE SOLUTIONS OF EXPERIMENTS I, II, AND III, PERIODICALLY DETERMINED EVERY THREE DAYS.

In the following tables are given the results of the analysis of every three-day culture solution. In the first column the solutions are numbered according to the diagram already given. In the next group of three columns is given the original concentration of each of these constituents, and in the following groups of three columns each, except the last group, the concentrations found at the ends of the several periods. In the last group of columns is given the average concentration based upon these analyses.

Tables VII and VIII give the results for Experiment I, in which 66 cultures were analyzed. The first table gives the results without dihydroxystearic acid, the second, those obtained when dihydroxystearic acid is present. The cultures with and without dihydroxystearic acid were, in this experiment, not grown at the same time, but in close succession. In Experiment II, the results of which are given in tables IX and X, the cultures with and without dihydroxy-

stearic acid were grown simultaneously, but the analysis is for six periods only and the number of solutions analyzed was reduced to 26 in each set, since it was impracticable to handle the complete number. In the third experiment, the results of which are given in Tables XI and XII, the same plan was followed as in Experiment II, except that the work was continued for only four periods. The average in this experiment is, therefore, given for the four periods only.

TABLE VII.—*Analytical results obtained in the 66 culture solutions of Experiment I, without dihydroxystearic acid, for eight periods of three days each.*

[In parts per million.]

Culture No.	Original concentration.			Concentration at end of—																									Average of eight periods.			Culture No.
				First period.			Second period.			Third period.			Fourth period.			Fifth period.			Sixth period.			Seventh period.			Eighth period.								
	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	
1	80	0	0	70.3	0	0	68.9	0	0	66.3	0	0	70.3	0	0	67.6	0	0	77.2	0	0	77.2	0	0	76.0	0	0	71.8	0	0	1
2	72	0	8	61.6	0	2.4	62.2	0	3.0	58.3	0	2.7	65.2	0	2.4	65.2	0	5.5	64.0	0	5.2	72.2	0	5.2	67.9	0	5.2	64.6	0	4.0	2
3	72	8	0	61.1	0	0	60.9	0	0	55.1	0	0	56.0	0	0	56.0	0	0	57.0	0	0	61.4	0.1	0	58.2	0	0	58.3	0	0	3
4	64	0	16	58.3	0	3.1	59.8	0	7.2	50.9	0	2.6	59.8	0	6.0	61.9	0	12.0	59.8	0	10.5	57.8	0	8.6	61.8	0	10.5	58.8	0	7.6	4
5	64	8	8	57.3	0	3.3	52.4	0	4.0	52.4	0	3.3	55.1	0	2.1	54.3	0	2.6	52.7	0	2.8	48.5	0	1.9	49.8	0	2.0	52.8	0	2.8	5
6	64	16	0	58.1	3.3	0	52.4	0	0	50.6	5.1	0	51.2	4.6	0	50.5	4.7	0	47.8	4.1	0	47.8	1.2	0	46.6	2.3	0	50.6	3.2	0	6
7	56	0	24	44.2	0	5.2	49.6	0	12.0	43.1	0	12.4	51.2	0	12.5	54.3	0	17.8	47.8	0	19.1	50.5	0	14.4	49.1	0	17.0	48.7	0	13.8	7
8	56	8	16	45.5	0	2.4	44.4	0	2.6	45.0	0	4.8	44.8	0	2.1	49.8	0	1.9	42.7	0	2.9	39.8	0.1	2.2	41.7	0	2.4	46.7	0	2.7	8
9	56	16	8	46.8	0.2	2.6	46.7	0	3.0	44.1	0	2.8	45.9	0	1.9	45.9	0	1.9	44.8	0	2.0	41.2	0	2.1	41.7	0	2.4	44.5	0	2.3	9
10	56	24	0	43.0	12.2	0	45.3	8	0	43.4	17.0	0	45.4	10.7	0	47.2	12.2	0	45.9	11.7	0	42.2	10.2	0	45.9	6.1	0	44.8	11.0	0	10
11	48	0	32	41.4	0	11.4	43.3	0	24.0	38.3	0	18.2	42.7	0	24.0	39.0	0	11.4	44.8	0	28.5	44.8	0	22.0	43.7	0	23.6	42.2	0	20.4	11
12	48	8	24	39.2	0	3.7	34.2	0	2.8	35.8	0	2.8	33.8	0	2.6	34.5	0	4.3	41.7	0	3.6	36.2	0.1	2.4	37.7	0	2.4	36.6	0	3.1	12
13	48	16	16	38.8	0.1	3.1	34.6	0	3.1	36.2	0	2.4	34.5	0	1.6	28.0	0	1.6	33.8	0	2.6	29.9	0	1.6	34.4	0	2.1	33.8	0	2.3	13
14	48	24	8	38.5	5.1	2.8	37.3	1.7	2.6	39.1	10.7	2.6	36.6	8.3	1.8	31.4	6.7	1.6	36.9	5.2	2.4	35.2	3.6	2.1	36.6	3.9	2.6	37.7	5.7	2.3	14
15	48	32	0	39.0	13.1	0	37.3	12.9	0	37.3	25.8	0	36.6	19.8	0	36.6	21.4	0	41.7	19.8	0	41.2	16.1	0	40.7	11.7	0	38.8	17.6	0	15
16	40	0	40	26.7	0	16.8	32.2	0	24.0	33.9	0	31.2	39.0	0	34.0	33.2	0	36.4	35.9	0	36.0	34.5	0	33.6	33.2	0	24.3	33.6	0	29.5	16
17	40	8	32	28.0	0	4.3	28.4	0	4.2	31.4	0	7.2	32.6	0.1	9.8	27.2	2.7	8.1	30.9	0.1	10.5	29.7	0.1	8.6	30.9	0	9.6	29.9	0.4	7.8	17
18	40	16	24	27.9	0.1	3.8	27.0	0	3.6	31.4	0	2.8	25.6	0	2.8	25.6	1.9	4.5	25.2	0	4.5	27.6	0.1	5.7	28.0	0	11.5	27.3	0.3	4.9	18
19	40	24	16	29.8	6.1	3.1	29.0	0.2	3.4	29.8	9.2	2.6	28.5	5.8	1.5	24.9	9.9	1.8	25.6	3.0	2.4	24.9	3.8	1.9	24.7	4.0	2.4	27.2	5.3	2.3	19
20	40	32	8	27.3	12.9	3.1	30.7	10.7	2.8	31.1	18.3	2.5	29.4	17.0	1.5	27.2	18.3	1.6	28.5	15.8	2.1	26.4	10.7	1.9	24.9	9.0	2.4	28.2	14.1	2.2	20
21	40	40	0	27.4	25.5	0	29.8	25.8	0	31.1	32.2	0	28.5	25.8	0	28.5	25.8	0	27.2	24.9	0	28.9	19.8	0	28.9	12.9	0	28.8	24.1	0	21
22	32	0	48	23.5	0	29.0	29.1	0	31.2	25.8	0	36.0	27.6	0	36.5	26.0	0	45.6	29.1	0	45.6	28.5	0	36.0	24.9	0	36.5	26.8	0	37.1	22
23	32	8	40	20.8	0	11.0	25.5	0	11.5	22.1	0.1	18.0	23.6	0.1	23.0	22.1	0.1	32.0	27.2	0.1	29.0	21.3	0.1	18.0	20.2	0.1	15.6	22.9	0.1	19.8	23
24	32	16	32	18.2	0.1	4.9	22.9	0	3.8	21.0	0	6.2	20.2	0	11.5	18.1	0	7.2	19.0	0	15.9	18.7	0	13.4	21.0	0	19.9	19.9	0	10.4	24
25	32	24	24	22.0	4.9	4.5	22.0	0	3.8	22.4	8.0	3.7	22.1	4.0	2.6	16.8	2.3	3.6	19.9	2.5	2.4	19.6	4.9	2.9	19.9	5.3	12.0	20.6	4.0	4.4	25
26	32	32	16	19.1	12.9	4.3	22.8	8.0	3.4	22.6	16.1	2.6	21.4	12.9	2.1	17.9	9.9	2.1	18.7	10.2	2.8	19.3	12.2	2.8	19.0	9.0	2.6	20.1	11.4	2.8	26
27	32	40	8	19.1	22.4	3.3	23.6	18.0	3.6	24.1	25.8	2.5	23.0	24.9	1.8	20.2	19.8	2.2	21.7	17.0	3.8	20.6	19.8	2.7	20.6	12.9	3.8	21.6	20.1	3.0	27
28	32	48	0	22.0	25.5	0	24.0	25.8	0	23.5	41.5	0	24.2	36.6	0	23.5	25.8	0	22.9	30.0	0	23.9	25.8	0	23.9	24.9	0	23.5	28.2	0	28
29	24	0	56	17.2	0	31.2	20.5	0	37.0	19.3	0	36.2	22.4	0	46.0	23.0	0	50.4	22.1	0	45.6	19.9	0	52.0	21.4	0	48.6	20.7	0	43.8	29
30	24	8	48	15.5	0	13.1	16.6	0.1	13.0	17.5	0.1	23.4	16.7	0.1	21.6	16.6	0	25.7	15.9	0.3	26.4	17.1	0.1	29.0	18.1	0.2	21.6	16.8	0.1	21.7	30
31	24	16	40	15.6	0.2	12.0	14.0	0	9.0	15.4	0	15.6	12.1	0	17.0	11.5	0	18.6	12.7	0	27.6	13.6	0	24.0	16.4	0	26.2	13.9	0	18.8	31

32	24	24	32	14.9	3.2	4.4	14.9	0	3.6	12.0	5.8	4.8	13.6	7.5	10.5	11.9	4.0	5.7	13.6	1.5	13.4	14.2	5.3	15.3	17.6	5.1	23.0	14.1	4.1	10.1	32
33	24	32	24	14.0	12.7	4.8	15.4	1.8	4.4	12.6	12.9	3.3	13.2	10.7	3.1	9.6	7.9	3.6	12.5	7.9	2.4	11.3	12.2	1.9	13.6	8.5	7.1	12.8	9.3	3.8	33
34	24	40	16	13.9	16.0	3.0	16.4	11.7	3.3	17.2	18.3	2.4	15.8	17.0	1.9	16.6	18.3	2.4	16.6	19.8	2.8	18.7	25.8	5.6	21.0	10.7	15.6	17.0	17.2	4.6	34
35	24	48	8	12.8	25.5	5.2	16.9	18.0	4.0	17.7	25.8	2.5	14.8	25.8	1.7	14.0	25.8	2.1	16.1	25.8	2.8	16.1	30.0	1.9	15.8	12.9	3.6	15.5	23.3	3.0	35
36	24	56	0	15.1	28.3	0	18.2	25.8	0	18.5	51.6	0	18.3	42.8	0	20.6	40.0	0	20.6	26.6	0	21.4	40.0	0	18.1	24.9	0	18.9	35.0	0	36
37	16	0	64	7.2	0	38.4	14.9	0	51.0	13.5	0	48.0	13.9	0	48.0	15.5	0	50.0	14.9	0	60.0	14.6	0	57.5	13.9	0	41.8	13.6	0	49.3	37
38	16	8	56	6.9	0	24.0	9.4	0.1	24.0	5.9	0.1	31.2	10.7	0.1	40.8	13.3	0.2	29.0	10.3	0.2	36.0	12.0	0.1	36.0	11.1	0.1	41.0	10.0	0.1	32.8	38
39	16	16	48	5.8	0	9.2	7.8	0	15.6	6.6	0	29.2	8.9	0	33.6	9.2	0	24.0	7.3	0	37.0	13.3	0.1	36.0	13.3	0	37.0	9.0	0	27.7	39
40	16	24	40	7.9	4.2	9.6	9.0	0.1	9.1	8.4	11.7	18.0	8.5	10.7	20.4	10.8	8.0	20.1	10.2	5.2	24.0	9.3	4.0	24.0	10.7	3.9	26.3	9.4	6.0	18.9	40
41	16	32	32	8.4	14.1	4.5	7.7	7.4	3.0	8.4	16.1	5.2	6.2	10.7	8.6	4.5	9.5	7.6	4.7	3.0	9.5	5.6	8.0	9.6	7.0	6.4	15.3	6.6	9.4	7.8	41
42	16	40	24	8.1	14.9	8.6	6.6	12.9	6.2	8.0	19.5	4.4	6.7	21.4	2.6	7.0	15.8	4.2	9.6	11.7	4.5	5.8	17.0	5.7	9.9	9.9	14.4	7.7	15.4	6.3	42
43	16	48	16	8.2	16.0	4.5	9.7	25.8	4.5	8.0	32.2	2.8	7.7	25.8	1.9	6.0	21.4	3.0	6.6	21.4	3.9	6.8	25.8	2.6	8.0	12.9	3.6	7.6	22.4	3.4	43
44	16	56	8	8.2	25.5	6.0	11.3	29.3	3.1	10.1	42.8	2.4	8.3	36.6	1.8	7.8	31.2	4.0	8.1	40.0	4.8	7.7	36.6	2.8	9.0	24.9	3.3	8.8	33.4	3.5	44
45	16	64	0	8.8	28.3	0	11.2	32.2	0	9.1	58.5	0	9.2	47.7	0	12.2	47.7	0	12.5	51.6	0	12.0	51.6	0	12.5	25.8	0	10.9	42.9	0	45
46	8	0	72	4.9	0	41.2	8.1	0	53.0	8.0	0	55.0	6.6	0	41.0	7.9	0	58.0	9.3	0	62.2	7.8	0	65.0	7.3	0	62.0	7.5	0	54.7	46
47	8	8	64	1.6	0	22.8	4.8	0.1	28.2	4.3	0.1	31.0	2.5	0.1	36.0	3.2	0.1	36.0	3.7	0.1	36.0	3.3	0.2	36.0	4.0	0.2	36.0	3.4	0.1	32.8	47
48	8	16	56	3.2	1.9	14.4	0.7	0	26.0	1.2	0	36.0	1.6	0	40.8	1.5	0	38.4	1.6	0	45.6	1.6	0.1	40.0	4.7	0	48.0	2.0	0.2	36.2	48
49	8	24	48	4.2	4.8	11.4	1.9	0.1	13.0	2.1	12.9	36.0	1.5	9.5	29.0	2.5	7.0	33.6	3.0	2.7	36.0	2.5	6.4	36.0	2.8	5.8	37.0	2.6	6.2	29.0	49
50	8	32	40	3.4	9.0	8.6	1.8	6.4	9.0	2.2	16.1	16.8	1.1	10.7	14.6	1.3	9.9	17.0	2.5	8.0	19.2	1.6	10.7	15.6	3.4	8.5	23.8	2.2	9.9	15.6	50
51	8	40	32	3.1	12.9	7.4	1.3	12.9	4.8	0	21.4	6.2	1.1	18.3	10.0	1.4	16.1	9.8	2.3	18.3	12.3	1.8	14.2	10.0	1.8	9.9	19.0	1.6	15.5	9.9	51
52	8	48	24	3.2	17.1	6.7	1.3	18.3	4.8	0.2	28.3	3.8	1.1	24.9	3.0	1.3	21.4	2.8	1.6	19.8	2.9	2.5	21.4	3.8	4.0	12.9	14.3	1.9	20.5	5.3	52
53	8	56	16	3.9	28.3	5.5	2.7	25.8	4.3	0.5	42.8	2.6	1.3	36.6	2.0	1.9	27.8	2.6	2.0	25.8	3.7	3.3	28.3	4.7	3.3	24.9	9.6	2.4	30.0	4.4	53
54	8	64	8	4.6	36.6	6.0	2.9	34.8	3.3	1.1	58.5	3.6	1.2	51.6	1.7	1.5	36.6	3.8	2.5	36.6	3.8	1.6	42.8	3.3	1.6	25.8	4.1	2.1	40.4	3.7	54
55	8	72	0	4.5	45.6	0	2.5	49.7	0	4.3	71.4	0	1.7	71.4	0	2.1	51.6	0	4.6	51.6	0	4.4	51.6	0	3.8	25.8	0	3.5	52.3	0	55
56	0	0	80	0	0	57.6	0	0	60.0	0	0	60.0	0	0	55.0	0	0	77.0	0	0	72.0	0	0	74.9	0	0	57.8	0	0	64.4	56
57	0	8	72	0	0	43.6	0	0	43.0	0	0	53.0	0	0	53.0	0	1.8	57.6	0	4.3	57.3	0	0	62.1	0	0	57.2	0	0.8	53.4	57
58	0	16	64	0	0	22.8	0	0	27.0	0	0	41.0	0	0	46.0	0	3.0	41.0	0	2.5	48.0	0	0.1	50.4	0	1.8	41.0	0	0.9	39.7	58
59	0	24	56	0	0.1	18.4	0	0	18.0	0	6.4	29.1	0	8.3	36.0	0	10.7	36.0	0	10.7	50.0	0	9.5	48.0	0	4.0	41.0	0	6.2	34.6	59
60	0	32	48	0	1.8	10.3	0	2.3	9.6	0	16.1	29.0	0	15.3	33.6	0	17.0	36.0	0	16.1	41.0	0	19.8	36.0	0	9.9	36.0	0	12.4	28.9	60
61	0	40	40	0	1.9	10.3	0	10.0	9.0	0	21.4	15.8	0	21.4	19.9	0	25.8	29.0	0	18.3	29.0	0	25.8	26.4	0	12.9	26.2	0	17.2	20.7	61
62	0	48	32	0	16.6	7.8	0	25.8	5.0	0	25.8	10.3	0	28.3	15.3	0	34.3	17.2	0	25.8	15.9	0	36.6	22.0	0	16.1	23.6	0	26.2	14.6	62
63	0	56	24	0	25.8	7.2	0	32.1	5.4	0	36.6	5.2	0	34.3	2.9	0	36.6	9.6	0	30.0	12.0	0	47.7	9.6	0	18.0	14.4	0	32.6	8.3	63
64	0	64	16	0	34.3	4.7	0	36.6	4.0	0	47.7	2.8	0	51.6	1.6	0	47.7	6.3	0	42.8	6.2	0	56.0	4.8	0	25.8	8.1	0	42.8	4.8	64
65	0	72	8	0	46.6	7.4	0	51.6	6.0	0	64.5	3.2	0	64.5	2.0	0	61.6	3.4	0	51.6	2.6	0	71.4	2.8	0	36.6	4.1	0	56.1	3.9	65
66	0	80	0	0	54.9	0	0	74.8	0	0	71.4	0	0	79.0	0	0	80.0	0	0	79.0	0	0	79.5	0	0	42.8	0	0	70.2	0	66

TABLE VIII.—*Analytical results obtained in the 66 culture solutions of Experiment I, with 50 parts per million of dihydroxystearic acid for eight periods of three days each.*

[In parts per million.]

Culture No.	Original concentration.			Concentration at end of—																							Average of eight periods.			Culture No.
				First period.			Second period.			Third period.			Fourth period.			Fifth period.			Sixth period.			Seventh period.			Eighth period.						
	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	
1	80	0	0	77.3	0	0	78.7	0	0	76.0	0	0	78.5	0	0	80	0	0	80	0	0	77.3	0	0	77.3	0	0	78.1	0	0	1
2	72	0	8	72.3	0	7.6	70.1	0	7.2	68.9	0	5.7	72.2	0	8.6	71.1	0	8.1	70	0	7.2	72.2	0	8.2	71.1	0	7.3	71.0	0	7.5	2
3	72	8	0	72.2	0	0	66.9	0	0	66.4	0	0	70.0	0	0	71.1	0	0	67.9	0	0	70.0	4.0	0	70.0	0	0	69.3	0.5	0	3
4	64	0	16	64.0	0	12.5	60.7	0	14.8	58.8	0	9.6	60.7	0	16.3	59.8	0	15.2	61.8	0	15.5	59.8	0	13.4	61.8	0	13.4	60.9	0	13.8	4
5	64	8	8	59.8	0	7.5	57.8	0	4.5	57.8	0	6.7	57.8	0	7.2	56.0	0	7.2	56.9	0	5.3	54.3	0	7.2	56.0	0	6.6	57.1	0	6.5	5
6	64	16	0	60.7	6.4	0	59.8	1.6	0	57.8	11.7	0	59.8	0.1	0	60.7	4.8	0	57.8	0.1	0	57.8	3.4	0	58.8	2.5	0	59.2	1.8	0	6
7	56	0	24	54.3	0	21.1	51.2	0	22.0	49.8	0	20.2	53.5	0	22.0	52.7	0	22.0	52.7	0	18.2	49.8	0	22.0	52.7	0	24.0	52.8	0	21.4	7
8	56	8	16	53.5	0.1	13.4	48.5	0	4.2	48.5	0.1	10.5	49.8	0	3.6	47.2	0.1	9.6	51.2	0	12.5	48.4	0	12.6	47.2	0	8.6	49.3	0	9.4	8
9	56	16	8	53.5	6.4	6.7	47.2	2.5	2.9	50.5	0.1	6.7	47.2	0	2.1	49.8	0.2	5.5	49.8	0	4.0	45.9	0.1	4.3	45.9	0	3.6	48.7	1.2	4.5	9
10	56	24	0	55.1	11.0	0	47.8	5.6	0	49.8	14.1	0	51.2	12.9	0	48.4	0.3	0	54.3	0.1	0	45.9	4.2	0	45.9	7.0	0	49.8	6.9	0	10
11	48	0	32	48.5	0	29.0	47.2	0	24.0	45.9	0	32.6	45.9	0	24.9	51.2	0	34.5	51.2	0	26.8	44.8	0	29.0	45.9	0	30.3	47.6	0	28.9	11
12	48	8	24	46.6	0.3	19.1	42.7	0	8.6	42.7	0.1	17.2	41.2	0.2	18.3	42.7	0.1	21.0	44.8	0.1	19.2	41.2	0	19.2	42.7	0.1	22.0	43.8	0.1	18.8	12
13	48	16	16	45.9	7.1	11.5	41.7	0.3	3.6	43.7	3.8	8.6	40.7	0	3.6	43.7	0.1	14.8	44.8	0	14.4	40.7	0.2	11.5	40.7	0	7.6	42.7	1.4	9.5	13
14	48	24	8	47.2	15.8	7.6	41.7	5.1	3.3	44.8	7.5	6.7	43.0	0.3	3.4	41.7	4.8	6.0	42.7	0.2	6.7	39.7	0.1	4.1	37.4	0	3.1	42.3	4.2	5.1	14
15	48	32	0	48.5	19.8	0	41.7	9.5	0	44.3	25.8	0	43.7	14.1	0	39.7	17.6	0	42.7	0.3	0	40.3	11.2	0	37.4	18.5	0	42.3	14.6	0	15
16	40	0	40	39.8	0	36.0	35.2	0	36.3	39.8	0	40.8	39.8	0	36.0	37.7	0	41.0	41.7	0	38.4	37.4	0	37.6	37.7	0	36.0	38.6	0	37.8	16
17	40	8	32	37.7	0.1	20.1	35.2	3.7	9.8	36.6	4.0	29.0	35.2	0.1	20.1	33.2	0.1	26.8	38.2	0	24.3	35.3	0.1	22.0	30.4	0	18.3	35.2	1.0	20.1	17
18	40	16	24	39.8	7.9	19.3	34.4	0.2	9.6	33.5	0.2	19.3	34.4	0	15.3	35.9	0.2	19.7	37.4	0	20.1	36.9	3.6	21.1	31.4	0.1	17.2	35.4	1.5	17.7	18
19	40	24	16	39.0	15.8	12.5	32.0	5.6	2.6	36.6	5.3	9.6	33.2	0.1	4.5	33.2	4.5	9.5	34.4	0	7.2	33.8	4.6	9.6	26.7	0	5.5	33.6	4.4	7.4	19
20	40	32	8	39.4	17.0	7.2	33.2	10.7	2.5	37.0	14.1	8.0	34.4	21.4	2.4	34.5	17.6	3.0	35.9	0.1	4.0	35.3	6.0	0.5	31.4	5.7	0.5	35.1	11.6	3.5	20
21	40	40	0	39.0	24.9	0	34.4	24.9	0	37.4	22.2	0	34.7	32.2	0	35.9	32.2	0	39.0	10.7	0	36.6	12.9	0	34.4	16.1	0	36.4	22.0	0	21
22	32	0	48	29.9	0	48.0	33.2	0	45.6	29.9	0	51.3	30.9	0	52.8	29.9	0	55.0	29.9	0	43.6	29.4	0	39.8	28.9	0	50.4	30.3	0	48.3	22
23	32	8	40	30.4	0.2	38.4	28.5	4.8	31.2	27.6	0.1	33.6	28.9	0.1	31.2	26.7	0.2	38.4	28.9	0	40.7	27.2	0.1	36.0	28.0	0.1	43.2	28.3	0.7	36.6	23
24	32	16	32	29.9	7.5	21.1	27.2	3.0	19.4	28.9	0.2	28.2	25.2	0.1	18.3	25.6	0.1	29.3	28.0	0	29.0	25.6	0.3	18.0	23.6	0	18.3	26.8	1.4	22.7	24
25	32	24	24	28.9	14.2	19.1	26.7	5.3	5.7	28.0	14.2	14.4	25.2	0.1	13.4	26.4	0.3	19.0	25.6	0	11.4	25.2	7.9	14.4	23.6	0.3	11.5	26.2	5.3	13.6	25
26	32	32	16	30.9	24.9	14.4	26.4	6.7	4.5	28.0	24.9	4.1	26.4	14.1	3.7	25.6	1.5	10.0	24.9	0.1	7.2	21.8	10.7	4.3	23.0	4.8	5.2	25.9	11.0	6.9	26
27	32	40	8	29.9	30.0	6.9	27.2	17.0	2.8	28.9	40.0	4.8	26.4	24.9	1.6	28.0	40.2	5.0	28.9	3.3	6.7	24.9	18.3	3.6	25.6	17.0	3.0	27.5	23.8	4.3	27
28	32	48	0	29.4	36.6	0	28.5	21.4	0	29.9	47.9	0	28.5	42.8	0	28.0	48.0	0	27.2	11.0	0	26.4	25.8	0	25.6	18.3	0	27.9	31.5	0	28
29	24	0	56	23.0	0	49.9	22.1	0	55.9	23.9	0	60.0	23.9	0	53.0	22.1	0	57.0	23.0	0	49.4	22.6	0	51.3	23.0	0	57.0	23.0	0	54.2	29
30	24	8	48	23.5	2.0	36.0	19.9	0.1	39.6	21.4	0.2	48.0	21.4	0.1	38.4	21.4	0.1	43.6	21.4	0.1	48.0	19.3	0.1	41.0	21.0	0.1	38.4	21.2	0.1	48 6	30

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TABLE IX.—*Analytical results obtained in 26 culture solutions of Experiment II, without dihydroxystearic acid, for six periods of three days each.*

[In parts per million.]

Culture No.	Original concentration.			Concentration at end of—																		Average of six periods.			Culture No.
				First period.			Second period.			Third period.			Fourth period.			Fifth period.			Sixth period.						
	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	
1	80	0	0	78.7	0	0	72.2	0	0	72.2	0	0	65.9	0	0	72.3	0	0	74.0	0	0	72.6	0	0	1
5	64	8	8	52.8	0	4.8	47.2	0	3.1	47.2	0	2.1	44.8	0	3.8	49.8	0	2.4	51.2	0	1.8	48.8	0	3.0	5
12	48	8	24	42.7	0	4.5	34.5	0	2.6	35.9	0	1.0	34.5	0.1	3.3	39.0	0	7.6	39.8	0	7.2	37.7	0	4.4	12
13	48	16	16	45.9	6.1	9.6	39.0	0	6.8	36.6	0.3	3.1	31.4	0.1	3.1	39.0	0.2	2.8	33.8	0.3	2.8	37.6	1.2	4.7	13
14	48	24	8	39.8	10.7	4.8	37.4	6.4	4.0	35.2	10.2	4.3	33.8	14.0	3.1	38.2	16.1	2.0	36.6	15.8	1.9	36.8	12.2	3.4	14
16	40	0	40	36.5	0	15.6	33.8	0	18.0	35.9	0	20.4	32.0	0	28.8	33.8	0	14.4	36.6	0	13.2	34.8	0	18.4	16
18	40	16	24	32.0	6.4	4.0	26.4	0.1	3.3	27.6	0.1	2.8	26.0	0.2	2.8	30.9	0	5.2	26.7	0	2.7	28.3	1.1	3.1	18
21	40	40	0	35.2	25.8	0	30.9	25.8	0	34.5	21.4	0	32.0	25.8	0	32.6	39.0	0	33.8	28.3	0	33.2	27.7	0	21
23	32	8	40	23.5	1.0	11.0	27.2	0.3	9.4	19.5	0	6.4	20.8	0.2	11.5	25.6	0	10.4	23.0	0	7.2	23.3	0.1	9.3	23
25	32	24	24	24.2	10.2	7.6	24.2	3.8	5.1	24.2	12.2	7.2	18.7	3.2	3.1	23.0	12.2	7.2	21.8	11.7	2.7	22.7	8.9	5.5	25
27	32	40	8	25.6	25.8	8.0	26.4	21.4	5.7	21.4	21.4	3.6	19.0	18.3	2.9	24.9	28.3	3.1	23.5	32.2	2.4	23.5	24.6	4.3	27
31	24	16	40	16.6	7.6	12.0	14.9	0.1	9.1	13.9	0.2	11.5	18.7	3.6	19.4	18.7	5.0	10.2	14.6	0.3	12.0	16.2	2.8	12.4	31
33	24	32	24	19.0	18.3	7.6	13.9	9.9	5.7	12.7	10.2	5.7	13.6	10.2	5.2	20.5	24.9	13.4	15.6	28.3	4.8	15.9	16.9	7.1	33
34	24	40	16	18.1	24.9	7.2	14.2	18.0	4.5	13.9	21.4	7.6	15.3	25.8	9.6	18.1	25.8	4.4	17.6	40.0	3.8	16.2	26.0	6.2	34
39	16	16	48	11.1	7.0	36.0	8.8	0.1	13.2	12.2	5.8	29.0	9.8	0.3	21.6	14.2	10.2	31.1	12.7	8.0	24.0	11.5	5.2	25.8	39
41	16	32	32	13.3	21.4	12.0	11.3	11.7	8.1	7.2	8.0	5.7	8.5	8.0	8.6	10.7	24.9	19.2	9.9	21.4	11.5	10.2	15.8	10.9	41
43	16	48	16	12.2	42.8	8.4	9.5	21.4	4.5	6.6	24.9	7.2	8.7	25.8	7.2	9.9	37.0	3.8	13.6	42.8	4.3	10.1	32.5	5.9	43
44	16	56	8	12.2	47.7	6.7	13.0	36.6	6.4	8.7	42.8	4.8	12.0	42.8	3.6	12.5	51.6	2.8	12.5	51.6	3.3	11.8	45.5	4.6	44
47	8	8	64	6.3	5.1	36.0	4.6	0.3	33.6	1.6	0.3	25.9	8.1	2.5	48.0	9.5	4.5	48.0	3.7	0.3	24.0	5.6	2.2	35.9	47
49	8	24	48	2.8	10.2	18.0	4.8	0	15.2	3.6	8.0	26.4	2.1	0.3	24.0	3.6	11.0	30.0	1.3	7.0	20.4	3.0	6.1	22.3	49
51	8	40	32	3.7	17.0	11.0	1.4	18.0	6.2	1.1	17.0	8.0	4.6	18.3	12.9	4.4	28.2	19.2	1.8	32.2	8.1	2.8	21.8	10.9	51
52	8	48	24	3.7	32.2	8.4	3.2	25.8	5.2	1.3	21.4	4.3	2.8	28.3	4.5	3.3	40.0	7.6	1.9	32.2	6.2	2.7	29.7	6.0	52
54	8	64	8	6.1	42.8	3.6	2.1	42.8	4.3	1.2	32.2	5.0	2.1	42.8	2.1	3.7	47.7	2.0	2.1	42.8	3.8	2.9	39.0	3.5	54
56	0	0	80	0	0	52.8	0	0	49.4	0	0	46.0	0	0	48.0	0	0	43.2	0	0	41.0	0	0	46.7	56
61	0	40	40	0	32.2	20.4	0	17.0	15.6	0	19.8	19.1	0	32.2	37.6	0	32.2	31.1	0	25.8	18.0	0	26.7	23.6	61
66	0	80	0	0	51.6	0	0	51.6	0	0	51.6	0	0	51.6	0	0	72.0	0	0	51.6	0	0	55.0	0	66

TABLE X.—*Analytical results obtained in 26 culture solutions of Experiment II, with dihydroxystearic acid, for six periods of three days each.*

[In parts per million.]

Culture No.	Original concentration.			Concentration at end of—																		Average of six periods.			Culture No.
				First period.			Second period.			Third period.			Fourth period.			Fifth period.			Sixth period.						
	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	
1	80	0	0	79.1	0	0	77.2	0	0	74.7	0	0	67.9	0	0	74.7	0	0	74.7	0	0	74.7	0	0	1
5	64		8	56.0	0	2.7	54.3	0	2.3	54.3	0	2.4	44.8	0	2.4	54.3	0	5.7	54.3	0	4.8	53.0	0	3.4	5
12	48	8	24	40.7	0	7.2	39.7	0	5.7	39.0	0	2.9	34.5	0.2	3.3	45.9	0	23.0	41.7	0	14.4	40.3	0	9.4	12
13	48	16	16	43.7	3.9	7.9	39.0	4.1	4.8	37.4	0	3.3	33.8	0.2	3.3	41.7	0	9.2	39.8	0.1	6.2	39.2	1.4	5.8	13
14	48	24	8	43.7	12.2	2.2	39.7	9.5	2.0	39.0	3.0	2.2	35.9	0.3	2.9	40.7	0.3	4.8	42.7	0.1	6.7	40.3	4.2	3.5	14
16	40	0	40	39.7	0	36.0	36.6	0	29.0	40.7	0	26.4	36.5	0	28.8	38.2	0	36.0	40.7	0	29.0	38.7	0.	30.9	16
18	40	16	24	39.0	6.4	6.1	33.2	4.1	9.8	33.5	0.1	4.8	29.4	0.2	6.2	35.2	0	19.2	34.5	0.1	12.3	34.1	1.8	9.7	18
21	40	40	0	34.7	25.8	0	37.4	24.0	0	36.5	15.8	0	33.2	8.5	0	36.5	24.9	0	37.4	21.4	0	36.0	16.5	0	21
23	32	8	40	26.4	0.1	18.0	24.9	0	20.4	21.8	0	8.4	19.6	0.1	16.8	28.0	0	31.2	29.9	0	29.0	25.1	0	20.6	23
25	32	24	24	26.4	9.0	6.2	23.0	5.8	9.8	21.4	0.3	7.4	18.3	0.3	6.2	26.4	3.0	14.4	25.6	3.0	9.1	23.5	3.6	8.9	25
27	32	40	8	26.4	25.8	2.8	25.6	18.0	5.7	28.9	10.7	7.2	23.0	17.0	4.2	29.9	17.0	7.2	28.0	25.8	8.1	27.0	19.1	5.8	27
31	24	16	40	23.9	8.5	18.0	18.7	2.4	21.0	18.1	0.3	18.0	13.6	0.3	21.6	20.5	0	33.8	18.7	0.1	23.2	18.9	1.9	22.6	31
33	24	32	24	21.4	17.0	14.4	18.7	15.8	9.8	13.9	2.5	4.8	14.9	0.3	12.6	20.5	3.0	19.2	18.1	7.0	10.5	17.9	7.6	11.9	33
34	24	40	16	23.0	21.4	15.8	17.0	19.8	7.2	14.2	14.2	4.8	14.6	7.1	5.3	19.9	17.0	12.6	21.4	18.0	10.5	18.1	16.3	9.4	34
39	16	16	48	15.3	7.6	18.0	13.9	2.5	22.8	7.6	0.1	30.6	9.2	0.3	24.0	12.5	0	30.6	10.8	0	26.4	11.6	1.7	25.4	39
41	16	32	32	14.2	17.0	9.1	11.3	14.2	10.5	7.6	3.9	5.2	7.5	4.6	9.6	13.0	8.0	24.9	12.7	6.4	21.1	11.1	8.9	13.4	41
43	16	48	16	14.6	25.8	12.5	11.5	25.8	6.2	12.0	4.9	6.7	9.9	18.0	6.2	14.6	15.8	13.4	14.9	17.0	11.4	12.9	17.9	9.4	43
44	16	56	8	14.6	32.2	3.4	14.2	42.8	3.1	9.2	14.0	3.3	11.7	24.9	4.3	17.6	25.8	9.6	16.1	17.0	9.6	13.9	26.1	5.5	44
47	8	8	64	7.1	1.8	31.2	6.8	0.3	38.4	4.0	0.1	25.9	3.0	1.6	43.2	8.0	0.3	55.2	8.0	0.3	53.0	6.2	0.7	42.8	47
49	8	24	48	7.7	12.8	31.2	5.7	6.7	23.2	1.3	0.3	31.6	2.9	0.3	26.4	3.3	2.9	31.2	6.1	0	31.1	4.5	3.8	29.1	49
51	8	40	32	7.2	25.8	10.3	4.2	21.4	8.7	2.2	6.7	7.2	4.0	3.0	19.2	8.0	8.3	29.0	7.8	5.1	22.0	5.6	11.7	16.1	51
52	8	48	24	6.6	34.3	10.3	3.3	25.8	7.7	1.3	24.9	5.7	5.0	2.7	23.0	8.7	18.3	23.0	8.3	7.0	17.3	5.5	18.8	14.5	52
54	8	64	8	8.7	42.8	3.2	5.2	42.8	4.3	3.3	28.3	3.1	4.6	21.4	4.1	7.6	32.2	7.6	8.7	18.0	6.2	6.4	30.9	4.7	54
56	0	0	80	0	0	48.0	0	0	54.8	0	0	62.0	0	0	60.0	0	0	67.2	0	0	42.2	0	0	55.7	56
61	0	40	40	0	25.8	31.2	0	21.4	24.0	0	9.5	31.1	0	18.3	37.6	0	30.0	33.0	0	25.8	31.2	0	21.8	31.5	61
66	0	80	0	0	51.6	0	0	42.8	0	0	47.7	0	0	51.6	0	0	58.0	0	0	64.0	0	0	52.6	0	66

TABLE XI.—*Analytical results obtained in 26 culture solutions of Experiment III, without dihydroxystearic acid, for four periods of three days each.*

[In parts per million.]

Culture No.	Original concentration.			Concentration at end of— First period.			Second period.			Third period.			Fourth period.			Average of four periods.			Culture No.
	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	
1	80	0	0	70.1	0	0	70.1	0	0	68.9	0	0	72.3	0	0	70.4	0	0	1
5	64		8	54.3	0	1.9	49.8	0	1.4	49.8	0	0.9	57.8	0	1.7	52.9	0	1.5	5
12	48	8	24	44.8	0	3.3	39.0	0	1.4	42.6	0.3	1.3	41.7	0	1.5	42.0	0.1	1.9	12
13	48	16	16	43.7	3.8	9.3	37.4	0.1	0.9	40.7	0.2	1.9	40.7	0.1	1.4	40.6	1.1	3.3	13
14	48	24	8	43.7	12.9	2.4	40.7	14.1	1.7	39.8	15.8	0.7	42.7	9.6	1.2	41.7	13.1	1.5	14
16	40	0	40	38.2	0	22.8	35.9	0	19.1	38.2	0	24.0	38.5	0	15.6	37.7	0	20.4	16
18	40	16	24	32.6	3.2	2.9	28.9	0	1.4	31.4	0.2	1.4	35.2	0	0	32.0	0.9	1.4	18
21	40	40	0	36.6	24.9	0	31.5	0	0	36.5	32.4	0	37.4	18.3	0	36.3	18.8	0	21
23	32	8	40	25.8	0	10.0	20.8	0	6.0	25.8	0.1	3.6	26.4	0	7.4	24.7	0	6.7	23
25	32	24	24	26.4	16.1	3.3	21.4	0.1	1.4	22.1	5.1	1.5	25.8	5.8	1.0	23.9	6.8	1.8	25
27	32	40	8	28.0	21.4	2.4	22.4	21.4	1.4	23.0	25.8	1.7	26.0	17.0	0.3	24.8	21.4	1.4	27
31	24	16	40	18.7	4.9	9.6	17.6	0	4.8	16.6	0.3	14.4	18.7	0.1	4.0	17.9	1.3	8.2	31
33	24	32	24	19.4	18.3	4.8	17.3	12.2	2.4	16.1	19.8	3.3	18.7	12.8	1.0	17.9	15.8	2.9	33
34	24	40	16	20.6	35.0	4.3	17.1	17.0	3.3	16.6	24.9	2.9	19.3	17.0	1.0	18.4	23.5	2.9	34
39	16	16	48	12.1	5.5	24.0	8.1	0	8.4	11.3	0.1	15.6	12.0	0.1	8.4	10.9	1.4	14.1	39
41	16	32	32	11.5	17.6	4.8	9.0	12.2	4.8	11.0	14.2	5.7	13.0	9.9	2.9	11.1	13.5	4.5	41
43	16	48	16	12.0	36.6	3.8	10.8	21.4	0.9	11.3	32.2	1.9	13.9	24.9	1.0	12.0	28.8	1.9	43
44	16	56	8	13.9	51.6	3.6	11.3	47.7	2.9	10.5	24.9	1.2	14.6	36.6	0.7	12.1	40.2	2.1	44
47	8	8	64	4.3	0.3	30.8	4.6	0.1	24.0	4.0	0.1	25.2	5.7	0.2	19.2	4.7	0.2	24.8	47
49	8	24	48	5.0	17.0	19.2	3.7	9.5	9.6	4.0	8.3	20.4	5.4	9.2	16.8	4.5	11.0	16.5	49
51	8	40	32	3.7	26.5	4.3	3.8	19.8	4.8	3.2	14.2	4.3	5.0	15.8	1.4	3.9	19.1	3.7	51
52	8	48	24	4.0	36.6	4.0	2.2	28.3	1.9	3.0	25.8	2.4	4.6	24.9	1.0	3.4	28.9	2.3	52
54	8	64	8	5.3	53.0	2.8	4.0	24.9	2.1	2.9	47.7	2.1	5.5	32.2	0.6	4.4	39.4	1.9	54
56	0	0	80	0	0	54.3	0	0	36.0	0	0	50.4	0	0	36.0	0	0	44.2	56
61	0	40	40	0	25.8	10.2	0	19.8	8.4	0	16.1	15.0	0	17.0	7.4	0	19.7	10.2	61
66	0	80	0	0	64.5	0	0	58.0	0	0	64.0	0	0	47.7	0	0	58.5	0	66

TABLE XII.—*Analytical results obtained in 26 culture solutions of Experiment III, with 50 parts per million of dihydroxystearic acid for four periods of three days each.*

[In parts per million.]

Culture No.	Original concentration.			Concentration at end of— First period.			Second period.			Third period.			Fourth period.			Average of four periods.			Culture No.
	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	P_2O_5.	NH_3.	K_2O.	
1	80	0	0	74.7	0	0	76.0	0	0	77.2	0	0	74.7	0	0	75.6	0	0	1
5	64	8	8	57.8	0	5.0	54.3	0	1.9	49.8	0	1.6	54.3	0	3.4	54.0	0	3.0	5
12	48	8	24	48.4	0.1	19.2	42.7	0	8.6	41.7	0	3.8	42.7	0	5.3	43.9	0	9.2	12
13	48	16	16	47.1	5.8	9.6	43.7	0.3	3.8	39.0	0.1	1.9	41.2	0	1.5	40.2	1.5	4.2	13
14	48	24	8	48.4	17.0	6.2	41.7	9.9	2.9	40.7	6.4	1.9	40.7	0.3	3.4	42.9	8.4	3.6	14
16	40	0	40	39.0	0	30.0	39.8	0	32.4	35.7	0	33.6	41.7	0	20.4	39.0	0	29.1	16
18	40	16	24	40.7	8.3	15.3	35.2	2.9	6.7	33.8	0.2	4.8	38.2	0.1	5.0	37.0	2.9	7.9	18
21	40	40	0	38.2	17.6	0	37.4	19.8	0	38.2	19.8	0	40.7	8.3	0	38.7	16.4	0	21
23	32	8	40	32.0	0.1	32.6	27.2	0.1	21.5	25.8	0.3	12.0	29.8	0	13.2	28.7	0.1	19.8	23
25	32	24	24	29.9	12.2	19.2	26.4	6.4	9.6	25.8	7.9	1.4	29.8	0.1	6.4	28.0	6.7	9.2	25
27	32	40	8	30.9	24.9	7.2	28.5	24.9	3.6	28.0	19.8	2.4	27.2	8.3	3.4	28.6	19.5	4.1	27
31	24	16	40	22.1	14.2	30.5	21.0	0.3	24.0	18.7	0.1	15.6	19.9	0.1	8.4	20.4	3.7	19.6	31
33	24	32	24	22.1	24.9	16.3	19.9	18.3	14.4	18.7	9.9	3.8	20.6	0.3	6.2	20.3	14.4	10.2	33
34	24	40	16	21.4	25.8	11.5	20.6	25.6	7.2	19.0	19.8	1.9	23.9	0.3	5.3	21.2	17.9	6.5	34
39	16	16	48	18.1	9.2	39.8	12.5	0.3	25.2	10.8	0.1	19.2	12.5	0.1	12.0	13.5	2.4	24.0	39
41	16	32	32	17.0	21.4	25.9	13.0	17.0	14.2	11.5	2.4	11.0	13.6	0.3	11.0	13.8	10.3	15.5	41
43	16	48	16	16.6	32.0	11.0	14.2	24.9	4.8	10.8	12.8	1.9	13.9	7.9	2.0	13.9	19.9	4.9	43
44	16	56	8	17.0	47.7	7.9	13.9	32.2	2.9	12.0	21.4	2.4	14.6	8.5	1.4	14.4	27.7	3.7	44
47	8	8	64	9.3	3.3	51.3	7.1	0.2	48.0	5.4	0.3	36.0	8.8	0.1	31.2	7.7	1.0	41.6	47
49	8	24	48	9.9	14.2	36.0	6.6	7.9	26.2	3.4	0.2	24.0	5.5	0.3	16.8	6.4	5.7	25.8	49
51	8	40	32	8.8	35.0	25.9	6.1	24.9	11.0	2.6	14.2	1.9	6.6	2.3	9.6	6.0	19.1	12.1	51
52	8	48	24	9.3	40.0	19.2	7.7	39.0	14.4	4.8	24.9	5.3	8.3	12.2	6.7	7.5	29.0	11.4	52
54	8	64	8	8.8	64.0	7.2	7.9	51.6	3.1	5.4	32.2	2.4	7.9	24.9	1.0	7.5	43.2	3.4	54
56	0	0	80	0	0	51.3	0	0	72.0	0	0	60.0	0	0	45.6	0	0	57.2	56
61	0	40	40	0	40.0	36.0	0	25.8	25.2	0	25.8	9.2	0	8.5	20.4	0	25.0	22.7	61
66	0	80	0	0	64.0	0	0	67.0	0	0	64.0	0	0	32.2	0	0	56.8	0	66

RELATION BETWEEN GROWTH OF CULTURES AND CONCENTRATION OF P_2O_5, NH_3, AND K_2O FOUND IN THE VARIOUS CULTURE SOLUTIONS.

The experimental results reported seem worthy of a closer analysis than that accorded them thus far. General tendencies as indicated by the individual cultures have already been pointed out, and these general impressions gleaned from the individual results can be better shown by a method of grouping, which in a large measure amounts to a multiplication of the results obtained in the individual cultures, as already pointed out. This method of grouping should be particularly

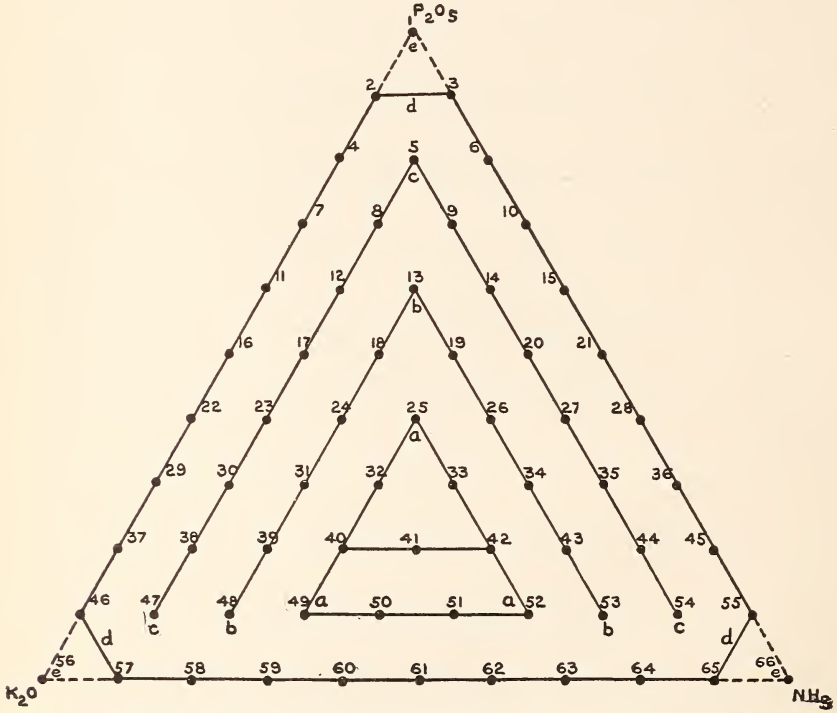

FIG. 31.—Showing the arrangement of the culture solutions in groups. (a, Group 1; b, Group 2; c, Group 3; d, Group 4, with two fertilizer elements; e, Group 5, with one fertilizer element.)

valuable in showing the general tendencies, either in regard to green growth or concentration differences connected therewith. Such a system of grouping, comparing different regions of the diagram, can be made in various ways.

The grouping shown in figure 31 was made because by so doing the area of the greatest growth, which was always somewhat below the center of the triangle, will fall in all of these experiments into the central group. This central grouping is shown in the diagram as Group 1, the connecting lines showing the cultures included in this group.

Group 2 takes in the cultures lying immediately outside of this central group. Group 3 is made up in the same way, except that it is farther removed from the central group. It will be noticed that the cultures in these three groups contain all three fertilizer constituents. The next, or fourth group, contains all of the culture solutions in which two fertilizer elements occur, as shown by the lines. The fifth and last group contains the culture solutions with single fertilizer elements.

In handling the data, therefore, the average green weight in grams for each of these groups was determined together with the average final concentration in the respective fertilizer constituents, or these combined.

GROWTH OF CULTURES AND CONCENTRATION OF $P_2O_5+NH_3+K_2O$ IN EXPERIMENT I.

In Table XIII the average green weight and combined concentration of the P_2O_5, NH_3, and K_2O is shown for Experiment I, without dihydroxystearic acid.

TABLE XIII.—*Average green weight and concentration of $P_2O_5+NH_3+K_2O$ obtained in different regions of the triangular diagram, figure 31. Experiment I, without dihydroxystearic acid.*

Grouping of culture solutions.	Number of cultures included.	Average green weight, in grams.	Relative green weight.	Average $P_2O_5+NH_3+K_2O$ content, in parts per million.		Percentage decrease in concentration of $P_2O_5+NH_3+K_2O$.
				Original.	Final.	
Group 1 (with three fertilizer elements)...	10	4.645	100	80	29.0	63.8
Group 2 (with three fertilizer elements)...	11	4.120	88	80	35.0	56.3
Group 3 (with three fertilizer elements)...	15	3.507	75	80	44.1	44.9
Group 4 (with two fertilizer elements).....	27	2.155	46	80	54.1	36.1
Group 5 (with one fertilizer element).....	3	1.502	34	80	68.8	14.0
Groups 1, 2, and 3 combined (with three fertilizer elements).....	36	4.010	.....	80	37.0	53.8
All cultures combined.....	66	3.137	.....	80	45.4	43.2

In the third column the relative green weight of the wheat plants for the different groups is given, taking the result in Group 1 as 100. From this it will be seen that the growth in Group 2 is 88 per cent of that in Group 1, and in Group 3 it is 75 per cent; in Group 4, with two fertilizer elements, it is 46 per cent, and in Group 5, with a single fertilizer element, the average result is only 34 per cent. The concentrations in these various groups are shown in the fifth column. The original concentration in all these cases was 80 parts per million of the combined constituents. In the first group, which was the one giving the greatest growth, the concentration was decreased from 80 to 29 parts per million, although, as has already been shown, the ratio of the three constituents in the solutions of this group suffered less change than did the ratio in the other groups. This can be

seen in figure 7. In the second group the concentration was reduced to 35 parts per million; in the third group of the three fertilizer constituents to 44 parts; in the group having two fertilizer constituents it was reduced to 54 parts per million; and in the group containing one fertilizer constituent it was reduced only to 69 parts per million as an average.

For the sake of comparison, a group containing all cultures having the three fertilizer elements, as well as the combination of the entire 66 cultures, is given. The table also very clearly shows the markedly different effects produced on the green weight by a single fertilizer element, and when these are used in combinations of two and of three, the results being approximately 1.5, 2.2, and 4, respectively, the higher group within the latter being as high as 4.6.

In Table XIV are shown the corresponding results obtained when the dihydroxystearic acid was present.

TABLE XIV.—*Average green weight and concentration of $P_2O_5+NH_3+K_2O$ obtained in different regions of the triangular diagram, figure 31. Experiment I, with 50 parts per million dihydroxystearic acid.*

Grouping of culture solutions.	Number of cultures included.	Average green weight, in grams.	Relative green weight.	Average $P_2O_5+NH_3+K_2O$ content, in parts per million.		Percentage decrease in concentration of $P_2O_5+NH_3+K_2O$.
				Original.	Final.	
Group 1 (with three fertilizer elements).....	10	2.878	100	80	45.5	43.0
Group 2 (with three fertilizer elements).....	11	2.320	83	80	50.3	37.0
Group 3 (with three fertilizer elements).....	15	1.835	64	80	57.0	28.8
Group 4 (with three fertilizer elements).....	27	1.099	37	80	68.2	14.7
Group 5 (with one fertilizer element).....	3	.772	27	80	76.9	3.9
Groups 1, 2, and 3 combined (with three fertilizer elements).....	36	2.273	.....	80	51.6	35.2
All cultures combined.....	66	1.724	.....	80	59.7	25.4

The relative green weights obtained in the different groups are very similar to those of the other set, except that the difference is more marked. The actual growth, however, made in each case is considerably less than when the dihydroxystearic acid was absent. This decrease in growth is least in Group 1, where in general the best conditions for growth appear to have existed. In this group the growth was decreased by only 38 per cent, whereas in Group 2 the growth was decreased 43 per cent, and in Group 3 it was decreased 48 per cent by this substance. In Group 4, with two fertilizer constituents, as well as in Group 5, with a single fertilizer constituent, it was about 49 per cent. The average green weight of all the 66 cultures was in the one case 3.1 and in the other about 1.7, giving a decrease in plant development of about 45 per cent as an average of all the cultures in the experiment. The fifth column, giving the average concentrations found by analysis of $P_2O_5+NH_3+K_2O$, shows that, with this decrease in green weight caused by the dihydroxystearic

acid, there was associated a higher concentration of the solution at the end of each period of growth. The average concentration in all the 66 culture solutions was, without the dihydroxystearic acid, reduced from 80 to 45 parts per million, and with the dihydroxystearic acid from 80 to 60 parts per million in this experiment.

GROWTH OF CULTURES AND PHOSPHATE CONCENTRATIONS IN EXPERIMENT I.

In the previous section the relation between the plant growth and the total concentration of the three fertilizer elements was discussed. It will also be of interest to consider this same grouping in respect to the concentrations of the fertilizer elements individually. The number of cultures included in the group where two fertilizer elements were used was necessarily reduced, inasmuch as the ingredient in question did not occur in all of the solutions, and the group of single fertilizer elements becomes of course reduced to only one culture, and for this reason has very little comparative value, although it is usually decided enough to allow no doubt as to the general effect.

TABLE XV.—*Average green weight and concentration of P_2O_5 obtained in different regions of the triangular diagram, figure 31. Experiment I, without dihydroxystearic acid.*

Grouping of culture solutions.	Number of cultures included.	Average green weight, in grams.	Relative green weight.	Average P_2O_5 content in parts per million.		Percentage decrease in concentration of P_2O_5.
				Original.	Final.	
Group 1 (with three fertilizer elements)	10	4.645	100	16.0	8.0	50.0
Group 2 (with three fertilizer elements)	11	4.120	88	26.0	16.3	37.3
Group 3 (with three fertilizer elements)	15	3.507	75	34.0	24.9	26.9
Group 4 (with two fertilizer elements)	18	1.531	33	40.0	33.0	17.5
Group 5 (with one fertilizer element)	1	.648	14	80.0	71.8	10.3
Groups 1, 2, and 3 combined (with three fertilizer elements)	36	4.010	.....	26.6	17.6	33.8

In the fifth column of Table XV are given the concentrations of P_2O_5 found after each period of growth, the original concentration being given in the fourth column for comparison. In the last column is shown the percentage decrease in the concentration of P_2O_5. This percentage decrease was, in the first group 50, in the second group 37, and in the third group 27 per cent. In the combination of two fertilizer elements, one of which was phosphate, it was 17.5 per cent, and in the phosphate by itself it was only 10 per cent. The actual decrease in concentration appears from the figures, however, to be strikingly uniform, varying in the different groups from 7 to 9 parts per million. This relationship of final to original concentration is, however, not properly shown by this form of grouping, and can be much more satisfactorily handled, as will be done later, by grouping only such phosphate solutions as have the same origi-

nal concentration. In the present table the original concentration is really an average of points varying, for instance, in the third group from 10 to 80 per cent in phosphate content, giving an average concentration of 34 parts per million.

In Table XVI the corresponding results obtained with dihydroxystearic acid are given, the table being in all other respects similar to the one just described.

TABLE XVI.—*Average green weight and concentration of P_2O_5 obtained in different regions of the triangular diagram, figure 31. Experiment I, with 50 parts per million dihydroxystearic acid.*

Grouping of culture solutions.	Number of cultures included.	Average green weight, in grams.	Relative green weight.	Average P_2O_5 content in parts per million.		Percentage decrease in concentration of P_2O_5.
				Original.	Final.	
Group 1 (with three fertilizer elements).....	10	2.878	100	16.0	12.3	23.4
Group 2 (with three fertilizer elements).....	11	2.320	83	26.0	21.6	16.7
Group 3 (with three fertilizer elements).....	15	1.835	64	34.0	29.6	12.9
Group 4 (with two fertilizer elements).....	18	.973	33	40.0	33.3	6.6
Group 5 (with one fertilizer element).....	1	.269	9	80.0	78.1	2.3
Groups 1, 2, and 3 combined (with three fertilizer elements).....	36	2.273	.....	26.6	22.3	16.0

As was the case with the total fertilizer ingredients, we find here that the concentration in phosphate is in all cases higher than in the groups of solutions without dihydroxystearic acid. This is shown especially by a comparison of the last columns where the percentage decreases are given. From this it will be seen that in Group 1, for instance, the percentage decrease in P_2O_5 was only 23 per cent, as compared with 50 per cent in the case of the solutions without dihydroxystearic acid. The same general result is shown by comparison with the other figures in these columns of the two tables.

GROWTH OF CULTURES AND NITRATE CONCENTRATIONS IN EXPERIMENT I.

In Tables XVII and XVIII are given the same character of results as have been given in the preceding section for phosphate, except that the concentration of nitrates is stated.

TABLE XVII.—*Average green weight and concentration of NH_3 obtained in different regions of the triangular diagram, figure 31. Experiment I, without dihydroxystearic acid.*

Grouping of culture solutions.	Number of cultures included.	Average green weight, in grams.	Relative green weight.	Average NH_3 content in parts per million.		Percentage decrease in concentration of NH_3.
				Original.	Final.	
Group 1 (with three fertilizer elements).....	10	4.645	100	32.0	9.8	69.4
Group 2 (with three fertilizer elements).....	11	4.120	88	26.9	7.9	70.4
Group 3 (with three fertilizer elements).....	15	3.507	75	22.5	5.8	59.9
Group 4 (with two fertilizer elements).....	18	2.721	58	40.0	22.8	43.1
Group 5 (with one fertilizer element).....	1	2.752	34	80.0	70.2	12.2
Groups 1, 2, and 3 combined (with three fertilizer elements).....	36	4.010	.....	26.6	8.9	66.5

TABLE XVIII.—*Average green weight and concentration of NH_3 obtained in different regions of the triangular diagram, figure 31. Experiment I, with 50 parts per million dihydroxystearic acid.*

Grouping of culture solutions.	Number of cultures included.	Average green weight, in grams.	Relative green weight.	Average NH_3 content in parts per million.		Percentage decrease in concentration of NH_3.
				Original.	Final.	
Group 1 (with three fertilizer elements)....	10	2.878	100	32.0	11.7	63.3
Group 2 (with three fertilizer elements)....	11	2.320	83	26.9	9.5	63.4
Group 3 (with three fertilizer elements)....	15	1.835	64	22.5	9.6	56.2
Group 4 (with two fertilizer elements).....	18	1.443	50	40.0	27.7	30.8
Group 5 (with one fertilizer element).....	1	1.640	57	80.0	74.6	6.7
Groups 1, 2, and 3 combined (with three fertilizer elements).....	36	2.273	.....	26.6	9.6	61.8

In the groups containing only two or one of the fertilizer elements only those cultures containing nitrate are considered. In the three groups comprising the three fertilizing ingredients the percentage decrease in nitrate is seen to be, respectively, 69, 70, and 60; in the two-fertilizer element group it is 43; and in the single element, 12. The solution containing dihydroxystearic acid, on the other hand, gave for the groups with three fertilizer elements 63, 63, and 56, respectively; for that with two fertilizer elements, 31; and for the single fertilizer element, 7. It will be noticed that a comparison of these two columns shows that the dihydroxystearic acid has not had anywhere near so marked an effect on these nitrate results as on the results with the other fertilizers, as will be shown later. This effect of the nitrate is also shown in the other experiments to even a greater degree, the indications being, in fact, that in these other experiments the conditions are in some of the groups at least sufficient to slightly reverse the results.

GROWTH OF CULTURES AND POTASSIUM CONCENTRATIONS IN EXPERIMENT I.

In Tables XIX and XX are given the results for the potash concentrations similarly grouped and arranged as in the preceding tables.

TABLE XIX.—*Average green weight and concentration of K_2O obtained in different regions of the triangular diagram, figure 31. Experiment I, without dihydroxystearic acid.*

Grouping of culture solutions.	Number of cultures included.	Average green weight, in grams.	Relative green weight	Average K_2O content in parts per million.		Percentage decrease in concentration of K_2O.
				Original.	Final.	
Group 1 (with three fertilizer elements)....	10	4.645	100	32.0	10.8	66.2
Group 2 (with three fertilizer elements)....	11	4.120	88	26.9	11.3	58.0
Group 3 (with three fertilizer elements)....	15	3.507	75	22.9	9.6	58.3
Group 4 (with two fertilizer elements).....	18	2.212	48	40.0	26.1	34.8
Group 5 (with one fertilizer element).....	1	1.106	24	80.0	44.3	44.6
Groups 1, 2, and 3 combined (with three fertilizer elements).....	36	4.010	.....	26.6	10.4	60.9

TABLE XX.—*Average green weight and concentration of K_2O obtained in different regions of the triangular diagram, figure 1. Experiment I, with 50 parts per million dihydroxystearic acid.*

Grouping of culture solutions.	Number of cultures included.	Average green weight in grams.	Relative green weight.	Average K_2O content in parts per million.		Percentage decrease in concentration of K_2O.
				Original.	Final.	
Group 1 (with three fertilizer elements)	10	2.878	100	32.0	21.5	32.9
Group 2 (with three fertilizer elements)	11	2.320	83	26.9	19.0	29.4
Group 3 (with three fertilizer elements)	15	1.835	64	22.9	17.4	24.2
Group 4 (with two fertilizer elements)	18	.882	32	40.0	37.4	6.5
Group 5 (with one fertilizer element)	1	.408	14	80.0	77.8	2.7
Groups 1, 2, and 3 combined (with three fertilizer elements)	36	2.273	.....	26.6	18.9	28.8

The percentage decrease in the cultures without dihydroxystearic acid is for the three fertilizer elements in the three groups 66, 58, and 58, respectively; for the two fertilizer elements, 35; and for the single fertilizer element, 45. In the cultures with the dihydroxystearic acid the percentage decrease was for the same groups 33, 29, 24, 7, and 3, respectively, thus showing the much lower decrease in the presence of the dihydroxystearic acid. The same effect was shown in the phosphate results, though it was not so marked, and it was still less marked in the case of the nitrate results, as already mentioned.

GROWTH OF CULTURES AND CONCENTRATIONS IN EXPERIMENT II.

Experiment II was, it will be remembered, similar to Experiment I, except that the two series of cultures with and without dihydroxystearic acid were grown simultaneously. In this experiment, furthermore, only 26 solutions from each of the sets were analyzed and for only six periods instead of eight, as in the previous experiment.

In Table XXI are found the results obtained by grouping the green weights in the same manner as for Experiment I just described.

TABLE XXI.—*Average green weight and concentration of $P_2O_5+NH_3+K_2O$ obtained in different regions of the triangular diagram, figure 31. Experiment II, without dihydroxystearic acid.*

Grouping of culture solutions.	Complete groups.			Cultures analyzed.			Average $P_2O_5+NH_3+K_2O$ content in parts per million.		Percentage decrease in concentration of $P_2O_5+NH_3+K_2O$.
	Number of cultures.	Average green weight in grams.	Relative green weight.	Number of cultures.	Average green weight in grams.	Relative green weight.	Original.	Final.	
Group 1 (with three fertilizer elements)	10	3.088	100	6	3.105	100	80	36.5	54.4
Group 2 (with three fertilizer elements)	11	2.834	91	6	2.771	88	80	41.1	48.6
Group 3 (with three fertilizer elements)	15	2.135	68	8	2.258	71	80	47.8	40.3
Group 4 (with two fertilizer elements)	27	1.390	45	3	1.543	49	80	54.8	31.5
Group 5 (with one fertilizer element)	3	1.034	33	3	1.034	33	80	58.1	27.4
Groups 1, 2, and 3 combined (with three fertilizer elements)	36	2.613	.....	20	2.660	.....	80	42.4	47.0
All cultures combined	66	2.040	.....	26	2.340	.....	80	45.7	41.9

The first set of three columns gives the green-weight results for the complete groups; the second set of three columns gives results only for such cultures as were analyzed within each group, and the number of such cultures contained in each group is there given. The number of individual cultures which were analyzed can be obtained by comparing the two diagrams, figures 3 and 12. These were, for Group 1, cultures 25, 33, 41, 49, 51, and 52; for Group 2, cultures 13, 18, 31, 34, 39, and 43; for Group 3, cultures 5, 12, 14, 23, 27, 44, 47, and 54; for Group 4 with two fertilizer elements, cultures 16, 21, and 61; for Group 5 with a single element, cultures 1, 56, and 66. A comparison of the relative green weights contained in the entire group with the results obtained from the smaller number of cultures analyzed shows on the whole a very fair agreement, thus indicating that comparatively accurate relationships between the groups were obtained with the smaller number of cultures chosen. A further comparison of these relative green weights with those obtained in Experiment I contained in Table XIII shows that the results are in these two experiments very similar.

In the next to the last column are found the average concentrations obtained within each of these groups. In Group 1 the concentration was reduced from 80 to approximately 37 parts per million, or a decrease of about 54 per cent, while in the second group the concentration was reduced to 41 parts per million, a decrease of 49 per cent, and in the third group it was reduced only to 48 parts per million, or a decrease of 40 per cent. This experiment shows, therefore, the same general tendency as was exhibited in Experiment I, and the same is true of the other groupings made.

In Table XXII are given the results obtained with 50 parts per million of dihydroxystearic acid present in each culture.

TABLE XXII.—*Average green weight and concentration of $P_2O_5+NH_3+K_2O$ obtained in different regions of the triangular diagram, figure 31. Experiment II, with 50 parts per million dihydroxystearic acid.*

Grouping of culture solutions.	Complete groups.			Cultures analyzed.			Average $P_2O_5+NH_3+K_2O$ content in parts per million.		Percentage decrease in concentration of $P_2O_5+NH_3+K_2O$.
	Number of cultures.	Average green weight in grams.	Relative green weight.	Number of cultures.	Average green weight in grams.	Relative green weight.	Original.	Final.	
Group 1 (with three fertilizer elements)	10	2.173	100	6	2.265	100	80	36.1	54.9
Group 2 (with three fertilizer elements)	11	1.868	86	6	1.681	74	80	43.1	46.1
Group 3 (with three fertilizer elements)	15	1.190	55	8	1.301	57	80	48.6	39.3
Group 4 (with two fertilizer elements)	27	.796	37	3	.818	36	80	58.5	28.9
Group 5 (with one fertilizer element)	3	.648	29	3	.648	28	80	61.0	23.8
Groups 1, 2, and 3 combined (with three fertilizer elements)	36	1.670	.....	20	1.704	.....	80	43.2	46.0
All cultures combined	66	1.266	.....	26	1.480	.....	80	47.0	41.3

Here again the relative green weights obtained in the entire set of cultures as compared with the relative green weights contained in the smaller number of cultures analyzed are very similar. A comparison of these results with Experiment I, given in Table XIV, will show a very fair agreement.

A comparison of Tables XXI and XXII again shows, as in Experiment I, that the dihydroxystearic acid interfered with the development of the plants in all of these groups. This decrease in growth is again least in Group 1, where the depression was 27 per cent; in Group 2, it was 39 per cent; in Group 3, 42 per cent; in Group 4, with two fertilizer constituents, 47 per cent; and in Group 5, with one fertilizer constituent, only 37 per cent. All of these results are similar to those obtained in Experiment I, except that in no case was the depression as great. Taking all the 66 points in each set under consideration, it is seen that the average green weight without the dihydroxystearic acid was about 2.3 and with the dihydroxystearic acid about 1.5, giving a decrease in plant development of about 38 per cent as an average of all the cultures. In Experiment I it was 45 per cent.

In the next to the last column is given the average final concentration of all three fertilizer constituents. In the last column is given the decrease stated as a percentage. A comparison of these two columns with the same columns in the preceding table, giving the results where dihydroxystearic acid was absent, shows that the percentage decrease was less where the dihydroxystearic acid was present, but the differences are very slight. While this is true for the total of the groups with three fertilizer constituents, the further analysis of the following tables giving the results for the P_2O_5, NH_3, and K_2O separately will show that this similarity is due to the decrease in concentration of the nitrate, the decrease in the concentration of the phosphate and potassium being in every respect similar to that observed in the first experiment.

In Tables XXIII and XXIV are given the results similarly handled for the P_2O_5 alone.

TABLE XXIII.—*Average green weight and concentrations of P_2O_5 obtained in different regions of the triangular diagram, figure 31. Experiment II, without dihydroxystearic acid.*

Grouping of culture solutions.	Complete groups.			Cultures analyzed.			Average P_2O_5 content in parts per million.		Percentage decrease in concentration of P_2O_5.
	Number of cultures.	Average green weight in grams.	Relative green weight.	Number of cultures.	Average green weight in grams.	Relative green weight.	Original.	Final.	
Group 1 (with three fertilizer elements)	10	3.088	100	6	3.105	100	16.0	9.6	40.0
Group 2 (with three fertilizer elements)	11	2.834	91	6	2.771	88	28.0	19.9	28.9
Group 3 (with three fertilizer elements)	15	2.135	68	8	2.258	72	32.0	23.8	25.6
Group 4 (with two fertilizer elements)	18	1.040	33	2	.726	23	40.0	34.0	15.0
Group 5 (with one fertilizer element)	1	.700	22	1	.700	22	80.0	72.6	9.3
Groups 1, 2, and 3 combined (with three fertilizer elements)	36	2.613	.....	20	2.660	.....	26.0	18.4	29.2

TABLE XXIV.—*Average green weight and concentrations of P_2O_5 obtained in different regions of the triangular diagram, figure 31. Experiment II, with 50 parts per million dihydroxystearic acid.*

Grouping of culture solutions.	Complete groups.			Cultures analyzed.			Average P_2O_5 content in parts per million.		Percentage decrease in concentration of P_2O_5.
	Number of cultures.	Average green weight in grams.	Relative green weight.	Number of cultures.	Average green weight in grams.	Relative green weight.	Original.	Final.	
Group 1 (with three fertilizer elements)	10	2.173	100	6	2.265	100	16.0	11.4	28.7
Group 2 (with three fertilizer elements)	11	1.868	86	6	1.681	74	28.0	22.5	19.6
Group 3 (with three fertilizer elements)	15	1.190	55	8	1.301	57	32.0	26.5	17.2
Group 4 (with two fertilizer elements)	18	.601	27	2	.562	24	40.0	37.3	6.7
Group 5 (with one fertilizer element)	1	.510	23	1	.510	22	80.0	74.7	6.7
Groups 1, 2, and 3 combined (with three fertilizer elements)	36	1.670	.....	20	1.704	.....	26.0	20.8	20.0

It will be seen that the concentration in Group 1 was reduced from 16 to 9.6 parts per million, whereas in the case of the dihydroxystearic acid it was reduced from 16 to only 11.4. The same general comparison holds for all of the other groups, the percentage of reduction being in the first group 40 and 29, respectively; in the second group, 30 and 20, in the third group, 26 and 17, in Group 4, with two fertilizer elements, approximately 15 and 7, and in Group 5, with one fertilizer element, 9 and 7.

With the nitrogen results, similarly grouped in Tables XXV and XXVI, the order is reversed, the percentage decrease in nitrate being greater with dihydroxystearic acid in each case.

TABLE XXV.—*Average green weight and concentrations of NH_3 obtained in different regions of the triangular diagram, figure 31. Experiment II, without dihydroxystearic acid.*

Grouping of culture solutions.	Complete groups.			Cultures analyzed.			Average NH_3 content in parts per million.		Percentage decrease in concentration of NH_3.
	Number of cultures.	Average green weight in grams.	Relative green weight.	Number of cultures.	Average green weight in grams.	Relative green weight.	Original.	Final.	
Group 1 (with three fertilizer elements)	10	3.088	100	6	3.105	100	33.3	16.5	50.4
Group 2 (with three fertilizer elements)	11	2.834	91	6	2.771	88	25.5	11.5	54.9
Group 3 (with three fertilizer elements)	15	2.135	68	8	2.258	71	27.0	15.5	42.6
Group 4 (with two fertilizer elements)	18	1.646	53	2	1.800	58	40.0	27.2	32.0
Group 5 (with one fertilizer element)	1	1.370	44	1	1.370	44	80.0	55.0	31.3
Groups 1, 2, and 3 combined (with three fertilizer elements)	36	2.613	.....	20	2.660	.....	28.4	14.6	48.6

TABLE XXVI.—*Average green weight and concentrations of NH_3 obtained in different regions of the triangular diagram, figure 31. Experiment II, with 50 parts per million dihydroxystearic acid.*

Grouping of culture solutions.	Complete groups.			Cultures analyzed.			Average NH_3 content in parts per million.		Percentage decrease in concentration of NH_3.
	Number of cultures.	Average green weight in grams.	Relative green weight.	Number of cultures.	Average green weight in grams.	Relative green weight.	Original.	Final.	
Group 1 (with three fertilizer elements)	10	2.173	100	6	2.265	100	33.3	9.1	72.7
Group 2 (with three fertilizer elements)	11	1.868	86	6	1.681	74	25.5	6.8	73.3
Group 3 (with three fertilizer elements)	15	1.190	55	8	1.301	57	27.0	10.1	62.6
Group 4 (with two fertilizer elements)	18	.956	44	2	1.041	46	40.0	19.1	52.2
Group 5 (with one fertilizer element)	1	1.020	47	1	1.020	45	80.0	52.6	34.2
Groups 1, 2, and 3 combined (with three fertilizer elements)	36	1.670	.....	20	1.704	.....	28.4	8.8	69.0

Even in Experiment I it will be noticed that the nitrate results are closer together in the two sets than are the phosphate or the potassium results.

In Tables XXVII and XXVIII are given the results for potassium similarly grouped.

TABLE XXVII.—*Average green weight and concentration of K_2O obtained in different regions of the triangular diagram, figure 31. Experiment II, without dihydroxystearic acid.*

Grouping of culture solutions.	Complete groups.			Cultures analyzed.			Average K_2O content in parts per million.		Percentage decrease in concentration of K_2O.
	Number of cultures.	Average green weight in grams.	Relative green weight.	Number of cultures.	Average green weight in grams.	Relative green weight.	Original.	Final.	
Group 1 (with three fertilizer elements)	10	3.088	100	6	3.105	100	30.7	10.5	65.8
Group 2 (with three fertilizer elements)	11	2.834	91	6	2.771	88	26.6	9.7	63.5
Group 3 (with three fertilizer elements)	15	2.135	68	8	2.258	71	21.0	8.6	59.0
Group 4 (with two fertilizer elements)	18	1.477	48	2	1.740	56	40.0	21.0	47.5
Group 5 (with one fertilizer element)	1	1.033	33	1	1.033	33	80.0	46.7	41.6
Groups 1, 2, and 3 combined (with three fertilizer elements)	36	2.613	.....	20	2.660	.....	25.6	9.5	62.9

TABLE XXVIII.—*Average green weight and concentration of K_2O obtained in different regions of the triangular diagram, figure 31. Experiment II, with 50 parts per million dihydroxystearic acid.*

Grouping of culture solutions.	Complete groups.			Cultures analyzed.			Average K_2O content in parts per million.		Percentage decrease in concentration of K_2O.
	Number of cultures.	Average green weight in grams.	Relative green weight.	Number of cultures.	Average green weight in grams.	Relative green weight.	Original.	Final.	
Group 1 (with three fertilizer elements)	10	2.173	100	6	2.265	100	30.7	15.7	48.9
Group 2 (with three fertilizer elements)	11	1.868	86	6	1.681	74	26.6	13.7	48.5
Group (3 with three fertilizer elements)	15	1.190	55	8	1.301	57	21.0	12.0	42.9
Group 4 (with two fertilizer elements)	18	.831	38	2	.851	37	40.0	31.2	22.0
Group 5 (with one fertilizer element)	1	.415	19	1	.415	18	80.0	55.7	30.4
Groups 1, 2, and 3 combined (with three fertilizer elements)	36	1.670	.....	20	1.704	.....	25.6	13.6	46.9

Here again the effect of the dihydroxystearic acid is very marked, in the first group the reduction being approximately from 31 to 11 without and to 16 with the dihydroxystearic acid. The same general tendency is shown for the other groups as was the case in Experiment I.

The results of Experiment II are, therefore, very similar to those obtained in Experiment I, the only difference being a relative one in the case of nitrate decrease in the solutions containing dihydroxystearic acid. Experiment I shows an approach to equality in the two sets of columns, the one without dihydroxystearic acid, however, showing on the whole the greater final concentration, whereas in Experiment II the effect was much more marked, the nitrogen content being on the whole even lower than in the cultures where no dihydroxystearic acid was present.

GROWTH OF CULTURES AND CONCENTRATIONS IN EXPERIMENT III.

This experiment was similar to the preceding one in that only 26 culture solutions were analyzed, but the experiment was continued for only four periods. This will explain the lower green weights recorded in the following tables. The grouping of the results in these tables is the same as with Experiments I and II, already described. Comparing the relative green weights given in Table XXIX again shows that the 26 cultures chosen from the various groups or regions in the triangular diagram were representative of the groups as a whole.

TABLE XXIX.—*Average green weight and concentration of P_2O_5+NH_3+K_2O obtained in different regions of the triangular diagram, figure 31. Experiment III, without dihydroxystearic acid.*

Grouping of culture solutions.	Complete groups.			Cultures analyzed.			Average P_2O_5+NH_3+K_2O content in parts per million.		Percentage decrease in concentration of P_2O_5+NH_3+K_2O.
	Number of cultures.	Average green weight in grams.	Relative green weight.	Number of cultures.	Average green weight in grams.	Relative green weight.	Original.	Final.	
Group 1 (with three fertilizer elements)	10	2.725	100	6	2.689	100	80	32.0	60.1
Group 2 (with three fertilizer elements)	11	2.629	96	6	2.596	96	80	38.4	51.9
Group 3 (with three fertilizer elements)	15	2.122	78	8	2.096	78	80	40.6	49.1
Group 4 (with two fertilizer elements)	27	1.614	59	3	1.776	66	80	47.6	40.2
Group 5 (with one fertilizer element)	3	1.303	48	3	1.303	48	80	57.8	27.9
Groups 1, 2, and 3 combined (with three fertilizer elements)	36	2.445	.....	20	2.424	.....	80	36.0	55.0

The data of Table XXIX show exactly the same relations between the various groups as were shown in Experiments I and II. The same differences between the various groups are shown in the total concentration of the three fertilizer elements as was shown by the results of Experiments I and II.

Table XXX gives the result obtained with dihydroxystearic acid solutions.

TABLE XXX.—*Average green weight and concentration of $P_2O_5+NH_3+K_2O$ obtained in different regions of the triangular diagram, figure 31. Experiment III, with 50 parts per million dihydroxystearic acid.*

Grouping of culture solutions.	Complete groups.			Cultures analyzed.			Average $P_2O_5+NH_3+K_2O$ content in parts per million.		Percentage decrease in concentration of $P_2O_5+NH_3+K_2O$.
	Number of cultures.	Average green weight in grams.	Relative green weight.	Number of cultures.	Average green weight in grams.	Relative green weight.	Original.	Final.	
Group 1 (with three fertilizer elements)	10	1.733	100	6	1.664	100	80	41.4	48.2
Group 2 (with three fertilizer elements)	11	1.522	88	6	1.568	94	80	43.8	45.2
Group 3 (with three fertilizer elements)	15	1.425	82	8	1.391	84	80	52.0	35.1
Group 4 (with two fertilizer elements)	27	1.083	62	3	1.163	70	80	57.4	28.2
Group 5 (with one fertilizer element)	3	.936	54	3	.936	56	80	63.2	21.0
Groups 1, 2, and 3 combined (with three fertilizer elements)	36	1.521	.....	20	1.526	.....	80	46.2	42.1

The relative green weights obtained in the complete groups when compared with the relative green weights obtained in the cultures analyzed within these groups again show that these were representative of the entire group. They also show similar differences between the groups as in previous comparisons of this kind. Here again the effect of the dihydroxystearic acid was markedly to decrease plant development in all the groups. When this is expressed as a percentage, the decrease of growth becomes, for the first group, approximately 38 per cent; for the second group, 39 per cent; for the third group, 34 per cent; for the group with two fertilizer elements, 35 per cent; for the single-element group, 28 per cent. The order of the depression shown by these various groups is in this experiment somewhat different from that shown in the other two experiments. This is probably due to the fact that the full action of the dihydroxystearic acid had not been felt in these cultures inasmuch as the total quantity applied in the four changes was only half of that which had been applied to the other cultures in the eight changes. The next to the last column gives the average final concentration in the three fertilizer constituents and shows, as in all the other experiments, that the reduction was greatest in the first group, next in the second group, third in the third group, fourth in the group with two fertilizer elements, and fifth in the group having only a single fertilizer element. The same is shown in the table of the results with the dihydroxystearic acid. A comparison of these results with the ones obtained where the

dihydroxystearic acid was absent again shows that generally the dihydroxystearic acid solutions were not reduced so much in concentration as were those without this substance.

In Tables XXXI and XXXII the material is handled in the same manner for the concentration of the phosphate in the solutions.

TABLE XXXI.—*Average green weight and concentration of P_2O_5 obtained in different regions of the triangular diagram, figure 31. Experiment III, without dihydroxystearic acid.*

Grouping of culture solutions.	Complete groups.			Cultures analyzed.			Average P_2O_5 content in parts per million.		Percentage decrease in concentration of P_2O_5.
	Number of cultures.	Average green weight in grams.	Relative green weight.	Number of cultures.	Average green weight in grams.	Relative green weight.	Original.	Final.	
Group 1 (with three fertilizer elements)	10	2.725	100	6	2.689	100	16.0	10.6	33.7
Group 2 (with three fertilizer elements)	11	2.629	96	6	2.596	96	28.0	22.0	21.5
Group 3 (with three fertilizer elements)	15	2.122	78	8	2.096	78	32.0	26.0	18.8
Group 4 (with two fertilizer elements)	18	1.368	.....	2	1.349	.....	40.0	29.0	7.5
Group 5 (with one fertilizer element)	1	0.784	.....	1	0.784	.....	80.0	74.6	11.8
Groups 1, 2, and 3 combined (with three fertilizer elements)	36	2.445	.....	20	2.424	.....	26.0	20.2	22.4

TABLE XXXII.—*Average green weight and concentration of P_2O_5 obtained in different regions of the triangular diagram, figure 31. Experiment III, with 50 parts per million dihydroxystearic acid.*

Grouping of culture solutions.	Complete groups.			Cultures analyzed.			Average P_2O_5 content in parts per million.		Percentage decrease in concentration of P_2O_5.
	Number of cultures.	Average green weight in grams.	Relative green weight.	Number of cultures.	Average green weight in grams.	Relative green weight.	Original.	Final.	
Group 1 (with three fertilizer elements)	10	1.733	100	6	1.664	100	16.0	13.4	16.2
Group 2 (with three fertilizer elements)	11	1.522	88	6	1.568	94	28.0	24.6	12.1
Group 3 (with three fertilizer elements)	15	1.425	82	8	1.391	84	32.0	28.2	11.9
Group 4 (with two fertilizer elements)	18	0.958	55	2	0.965	58	40.0	38.6	3.6
Group 5 (with one fertilizer element)	1	0.805	46	1	0.805	48	80.0	75.6	5.4
Groups 1, 2, and 3 combined (with three fertilizer elements)	36	1.521	.....	20	1.526	.....	26.0	22.6	12.6

Besides the general effects which are again strikingly brought out in these and the subsequent tables, they also show the effect of the dihydroxystearic acid in preventing as great a decrease in the concentrations of the solutions.

Tables XXXIII and XXXIV give the results for the nitrate similarly compared.

TABLE XXXIII.—*Average green weight and concentration of NH_3 obtained in different regions of the triangular diagram, figure 31. Experiment III, without dihydroxystearic acid.*

Grouping of culture solutions.	Complete groups.			Cultures analyzed.			Average NH_3 content in parts per million.		Percentage decrease in concentration of NH_3.
	Number of cultures.	Average green weight in grams.	Relative green weight.	Number of cultures.	Average green weight in grams.	Relative green weight.	Original.	Final.	
Group 1 (with three fertilizer elements)	10	2.725	100	6	2.689	100	33.3	15.8	52.6
Group 2 (with three fertilizer elements)	11	2.629	96	6	2.596	96	25.5	9.7	61.9
Group 3 (with three fertilizer elements)	15	2.122	78	8	2.096	78	27.0	14.0	48.1
Group 4 (with two fertilizer elements)	18	1.793	65	2	2.069	77	40.0	39.3	51.7
Group 5 (with one fertilizer element)	1	1.757	64	1	1.757	65	80.0	58.6	26.7
Groups 1, 2, and 3 combined (with three fertilizer elements)	36	2.445	.....	20	2.424	.....	28.4	13.2	52.7

TABLE XXXIV.—*Average green weight and concentration of NH_3 obtained in different regions of the triangular diagram, figure 31. Experiment III, with 50 parts per million dihydroxystearic acid.*

Grouping of culture solutions.	Complete groups.			Cultures analyzed.			Average NH_3 content in parts per million.		Percentage decrease in concentration of NH_3
	Number of cultures.	Average green weight in grams.	Relative green weight.	Number of cultures.	Average green weight in grams.	Relative green weight.	Original.	Final.	
Group 1 (with three fertilizer elements)	10	1.733	100	6	1.664	100	33.3	13.7	58.9
Group 2 (with three fertilizer elements)	11	1.522	88	6	1.568	94	25.5	8.2	67.8
Group 3 (with three fertilizer elements)	15	1.425	82	8	1.391	84	27.0	12.5	53.7
Group 4 (with two fertilizer elements)	18	1.194	69	2	1.309	79	40.0	22.0	45.0
Group 5 (with one fertilizer element)	1	1.326	76	1	1.326	80	80.0	56.8	29.0
Groups 1, 2 and 3 combined (with three fertilizer elements)	36	1.521	.....	20	1.526	.....	28.4	11.6	59.1

As in Experiment II, the effect of the dihydroxystearic acid was to cause a somewhat greater decrease in the concentration of nitrate in all of the groups.

The results for potassium are given in the same manner in Tables XXXV and XXXVI and show, in harmony with all previous experiments, that the effect of the dihydroxystearic acid was to decrease the concentration of the solution in all the groups to a less extent than where this substance was absent. The remaining parts of the table show the same general effects as all the other tables.

TABLE XXXV.—*Average green weight and concentration of K_2O obtained in different regions of the triangular diagram, figure 31. Experiment III, without dihydroxystearic acid.*

Grouping of culture solutions.	Complete groups.			Cultures analyzed.			Average K_2O content in parts per million.		Percentage decrease in concentration of K_2O.
	Number of cultures.	Average green weight in grams.	Relative green weight.	Number of cultures.	Average green weight in grams.	Relative green weight.	Original.	Final.	
Group 1 (with three fertilizer elements)	10	2.725	100	6	2.689	100	30.7	5.0	83.4
Group 2 (with three fertilizer elements)	11	2.629	96	6	2.596	96	26.6	5.3	80.1
Group 3 (with three fertilizer elements)	15	2.122	78	8	2.096	78	21.0	5.3	75.0
Group 4 (with two fertilizer elements)	18	1.681	61	2	1.902	71	40.0	15.4	61.5
Group 5 (with one fertilizer element)	1	1.370	51	1	1.370	50	80.0	44.2	44.8
Groups 1, 2, and 3 combined (with three fertilizer elements)	36	2.445	.....	20	2.424	.....	25.6	5.3	.....

TABLE XXXVI.—*Average green weight and concentration of K_2O obtained in different regions of the triangular diagram, figure 31. Experiment III, with 50 parts per million of dihydroxystearic acid.*

Grouping of culture solutions.	Complete groups.			Cultures analyzed,			Average K_2O content in parts per million.		Percentage decrease in concentration of K_2O.
	Number of cultures.	Average green weight in grams.	Relative green weight.	Number of cultures.	Average green weight in grams.	Relative green weight.	Original.	Final.	
Group 1 (with three fertilizer elements)	10	1.733	100	6	1.664	100	30.7	11.1	64.8
Group 2 (with three fertilizer elements)	11	1.522	88	6	1.568	94	26.6	11.2	57.9
Group 3 (with three fertilizer elements)	15	1.425	82	8	1.391	84	21.0	11.1	47.1
Group 4 (with two fertilizer elements)	18	1.069	62	2	1.218	73	40.0	25.9	35.2
Group 5 (with one fertilizer element)	1	0.716	41	1	0.716	43	80.0	57.2	28.5
Groups 1, 2, and 3 combined (with three fertilizer elements)	36	1.521	.....	20	1.526	.....	25.6	12.0	.....

INFLUENCE OF DIFFERENT AMOUNTS OF P_2O_5, NH_3, AND K_2O, VARYING, RESPECTIVELY, FROM 8 TO 80 PARTS PER MILLION.

In the consideration of the results up to this point no special attention has been paid to the actual amounts of the individual fertilizer ingredients which were in the cultures. By reference to the original description of the diagram it will be seen, for instance, that there was a series of cultures in the line from number 46 to number 55 which contained 10 per cent of phosphate in the fertilizer mixture, or 8 parts per million of the culture solutions. Similarly,

the solutions in the line 37 to 45 contained 16 parts per million, in the line 29 to 36, 24 parts per million, and so on to the apex of the triangle. In the same manner the line of culture solutions from 3 to 57 contained 8 parts per million NH_3 as nitrate, the line 6 to 58, 16 parts per million, and so on up to 80 parts per million NH_3 in culture 66. The line of culture solutions from 2 to 65 contained 8 parts per million K_2O, line 4 to 64, 16 parts per million, and so on up to 80 parts per million K_2O in culture 56.

It will be interesting to see what effect these different amounts of each fertilizer ingredient have had on the growth of the plant and to study the removal of this constituent during the period of growth. In such a consideration it must always be borne in mind that there were present at the same time varying quantities of the other fertilizer constituents. For the purpose of such a comparison the growth of the cultures and the changes in concentration along any of these lines has been studied and is presented in this section. With this view all the results obtained in the various cultures in any one line were added together, and as the number of cultures naturally differ from line to line the average was determined in each case for comparison, although this average is not intended to mean that all the cultures along this line were similar, for it has already been shown that in general the points in the middle were higher than those at the end of any one of these lines.

INFLUENCE OF DIFFERENT AMOUNTS OF PHOSPHATE IN THE CULTURE SOLUTIONS OF EXPERIMENT I.

In Table XXXVII are given the results obtained for P_2O_5 in the cultures containing different amounts of P_2O_5 varying from 8 to 80 parts per million, as shown in the second column of the table.

TABLE XXXVII.—*Showing the results obtained for P_2O_5 in the cultures containing different amounts of P_2O_5, Experiment I.*

Per cent of P_2O_5 in fertilizer mixture.	P_2O_5 content in original solutions.	Without dihydroxystearic acid.					With dihydroxystearic acid.				
		Average P_2O_5 in final solutions.	Average decrease of P_2O_5.	Per centage decrease of P_2O_5.	Average green weight of cultures.	Decrease of P_2O_5 per unit of green weight.	Average P_2O_5 in final solutions.	Average decrease of P_2O_5.	Per centage decrease of P_2O_5.	Average green weight of cultures.	Decrease of P_2O_5 per unit of green weight.
	P. p. m.	*P. p. m.*	*P. p. m.*		*Grams.*	*P. p. m.*	*P. p. m.*	*P. p. m.*		*Grams.*	*P. p. m.*
100	80	71.8	8.2	10.3	0.648	12.7	78.1	1.9	2.4	0.269	7.0
90	72	61.5	10.5	14.6	1.226	8.6	70.1	1.9	2.6	0.556	3.4
80	64	54.1	9.9	15.5	1.983	5.0	59.1	4.9	7.7	0.835	5.9
70	56	46.2	9.8	17.5	2.580	3.7	50.1	5.9	10.5	1.335	4.4
60	48	37.8	10.2	21.3	3.045	3.3	43.7	4.3	8.9	1.438	3.0
50	40	29.2	10.8	27.0	3.340	3.2	35.7	4.3	10.8	1.685	2.6
40	32	22.2	9.8	30.6	3.295	3.0	27.5	4.5	14.1	1.966	2.3
30	24	16.2	7.8	32.5	3.308	2.3	19.8	4.2	17.5	2.268	1.9
20	16	9.2	6.8	42.5	3.558	2.9	13.5	2.5	15.6	1.971	1.3
10	8	2.9	5.1	63.8	3.640	1.4	6.2	1.8	22.5	2.391	0.8
0	0	.....	.....	.....	3.135	.....	.....	.....	.....	1.293	.....

The first column gives the percentage composition of the fertilizer mixture, so far as the P_2O_5 content was concerned. In the third column is given the average concentration for the eight three-day periods in the experiment, and in the fourth column the difference between this and the original concentration, thus giving the average decrease, which is expressed as a percentage in the fifth column on the basis of the original concentration. The sixth column gives the average green weight of the wheat plants obtained along any of these concentration lines, and the seventh column gives the decrease in P_2O_5 calculated to the unit basis of one gram production of green plant. In other words the decrease recorded in the fourth column has been divided by the green weight corresponding thereto in the sixth column. The following group of columns in the table gives the corresponding results obtained when 50 parts per million of dihydroxystearic acid was present in the culture solutions, similarly arranged and computed. It will be noticed that the green weight steadily increased as the phosphate content of the original solutions decreased. It must be borne in mind, of course, that when the phosphate content decreases, there is a corresponding increase in the average content of both potash and nitrogen. In the last figure for the green weight, however, namely, that in which the phosphate content became 0 in the culture solutions, there is again a marked drop, although the potash and nitrogen content in these was higher than in any of the solutions above this in the table. It accordingly follows that a very distinct part was played by the phosphate in producing growth, although its maximum efficiency seems to be reached in these experiments in rather low concentration. Attention might also be called here to the fact that the concentrations of phosphate in soil solutions are always low, and relatively much lower than those of either of the other constituents here considered. The plant in its natural environment has, therefore, adapted itself to growth in weak solutions of this constituent.

The increase in green weight shown by the table to be from 3.1 to 3.6 grams corresponded to an increase from 0 to 8 parts per million in the original P_2O_5 content. The further increase to 16 parts per million of P_2O_5 has produced no further increase in plant growth, and above this a decrease has followed which may be in part due to some direct influence of the phosphate solution, the carrier here used being calcium acid phosphate; or it may be due in part to the fact that the quantities of potash and nitrate are being decreased as the phosphate increases. This relation has, however, been discussed in a much more thorough manner where the ratios of these elements are considered; and the change in the concentrations which the solutions undergo, as shown in the diagram of ratio change in figure 7, makes this matter very clear. It is there shown that the region of better growth is

always found in the lower part of the diagram, as are also the region of greatest absorption and the region of least change in the ratio; i. e., in the solutions containing the lesser amounts of P_2O_5.

The average concentration in the culture solution after growth, as shown in the third column, continually decreases in phosphate content. The actual decrease in the next column, however, shows that the greatest decrease in concentration of this element does not go with the greatest growth, but is found in the 40 parts per million phosphate solutions, increasing steadily from the 8 parts per million solution to this point and then becoming practically constant up to the point where the other elements entirely disappear and only phosphate remains, when it again drops slightly, the conditions for growth also being much poorer through this total absence of potash and nitrogen. The decrease when expressed as a percentage of the amount of material originally present shows that the removal is the more complete as the concentration decreases. The last column in this section of the table, giving the decrease per unit of green weight, shows that equal weights of green plants cause quite unequal decreases in concentration, this change being least in the weaker solutions and greatest in the higher, thus indicating that more was removed by the plant in the higher concentrations than it could economically utilize under the conditions; i. e., the plant absorbed the material because it was there, although it apparently had already all that it could utilize economically. This is a fact consistent with field observations and ash analysis, where it is frequently noticed that the actual amount of plant-food constituents is larger in the poorer plants.

The results obtained with dihydroxystearic acid are in all respects similar to those discussed for the solutions not containing this substance. The green weight is, of course, as has already been repeatedly pointed out, in all cases smaller than the corresponding green weight where the substance was absent. The decrease observed, while showing the general trend, as in the preceding case, is much less, as is shown by a comparison of the first group of columns giving the average decrease and the percentage decrease. The same tendency is also shown by a comparison of the last column in each case showing a decrease of P_2O_5 per unit of green weight.

INFLUENCE OF DIFFERENT AMOUNTS OF NITROGEN IN THE CULTURE SOLUTIONS OF EXPERIMENT I.

Table XXXVIII gives the results obtained for nitrate in the cultures containing different amounts of nitrate similarly arranged and computed as in the phosphate table just discussed.

TABLE XXXVIII.—*Showing the results obtained for NH_3 in the cultures containing different amounts of NH_3, Experiment I.*

Per cent of NH_3 in fertilizer mixture.	NH_3 content in original solutions.	Without dihydroxystearic acid.					With dihydroxystearic acid.				
		Average NH_3 in final solutions.	Average decrease of NH_3.	Percentage decrease of NH_3.	Average green weight.	Decrease of NH_3 per unit of green weight.	Average NH_3 in final solutions.	Average decrease of NH_3.	Percentage decrease of NH_3.	Average green weight.	Decrease of NH_3 per unit of green weight.
	P. p. m.	*P. p. m.*	*P. p. m.*		*Grams.*	*P. p. m.*	*P. p. m.*	*P. p. m.*		*Grams.*	*P. p. m.*
100	80	70.2	9.8	12.3	2.752	3.6	65.9	14.1	17.6	1.640	8.5
90	72	54.2	17.8	24.7	2.699	6.6	62.4	9.6	13.3	1.531	6.3
80	64	42.0	22.0	34.3	3.046	7.2	50.2	13.8	21.6	2.034	6.8
70	56	32.8	23.2	41.4	3.169	7.3	36.9	19.1	34.1	2.275	8.4
60	48	24.1	23.9	49.8	3.492	6.8	27.9	20.1	41.8	2.419	8.3
50	40	18.3	21.7	54.2	3.685	5.9	21.3	18.7	46.2	2.219	8.4
40	32	12.0	20.0	62.5	4.166	4.8	13.2	18.8	58.8	2.522	7.4
30	24	6.1	17.9	74.6	3.852	4.6	6.5	17.5	72.9	2.378	7.4
20	16	0.5	15.5	96.3	3.893	4.0	2.6	13.4	83.9	1.736	7.7
10	8	0.2	7.8	97.5	3.156	2.5	.7	7.3	91.3	1.182	6.2
0	0	.....	.....	.....	.995	.....	.....	.....	.....	.398	.....

The green-weight column differs from the one discussed in the phosphate table, in that the highest result occurs with the fertilizer mixture containing 40 per cent NH_3, the numbers descending in each direction from this higher point. The change from 0 to 8 parts per million of NH_3 is very marked in the green weight, which increases from approximately 1 gram to 3.2 grams, an even greater change than was noted in the phosphate table. The average decrease in concentration was in this case again greatest between the limits of 32 to 64 parts per million, the increase being gradual from the 8 parts per million solution up to the 32 parts per million solution, then being practically uniform up to 64 parts per million, when it again declines. The figures in the percentage decrease column are on the whole much greater than those in the corresponding column in the phosphate table, thus showing a comparatively greater decrease of the nitrogen than of the phosphate in solutions of equal content of these elements, respectively. The last column, showing the decrease per unit of green weight, shows the same general tendency to decrease with the decrease in the original content of nitrogen in the solutions, as was noticed in the phosphate table, except that the first two results, namely in the 80 and 72 parts per million solutions, are in this case lower than the following three or four entries, while in the phosphate table these two were the highest in the column. The conditions for growth with the phosphate was in these two solutions, or groups, very poor as compared with the rest, while with the nitrate this difference in growth was not so apparent.

The general tendency of the results with the dihydroxystearic acid present in the solutions will be seen to be the same as those just discussed. The line of 32 parts per million cultures again gives the highest result in green weight and the difference between the 8 parts per

million cultures and the solutions containing no nitrogen whatever was again very marked. The last column in the table appears on the whole to show the same general tendency as the corresponding column in the first part of the table, but the differences are not so marked nor so regular.

INFLUENCE OF DIFFERENT AMOUNTS OF POTASH IN THE CULTURE SOLUTIONS OF EXPERIMENT I.

In Table XXXIX are given the results obtained for potassium in the cultures containing different amounts of potassium, the table being arranged and the results computed in the same manner as with those in preceding tables.

TABLE XXXIX.—*Showing the results obtained for K_2O in the cultures containing different amounts of K_2O, Experiment I.*

Per cent of K_2O in fertilizer mixture.	K_2O content in original solutions.	Without dihydroxystearic acid.					With dihydroxystearic acid.				
		Average K_2O in final solutions.	Average decrease of K_2O.	Percentage decrease of K_2O.	Average green weight.	Decrease of K_2O per unit of green weight.	Average K_2O in final solutions.	Average decrease of K_2O.	Percentage decrease of K_2O.	Average green weight.	Decrease of K_2O per unit of green weight.
	P.p.m.	*P.p.m.*	*P.p.m.*		*Grams.*	*P.p.m.*	*P.p.m.*	*P.p.m.*		*Grams.*	*P.p.m.*
100	80	64.4	15.6	19.5	1.106	14.1	81.4	0	.....	0.408	.....
90	72	54.1	17.9	24.8	1.922	9.3	64.6	7.4	10.3	.670	11.0
80	64	40.6	23.4	36.5	2.661	8.8	61.9	2.1	3.3	.893	2.3
70	56	36.9	19.1	34.1	2.890	6.6	51.7	4.3	7.7	1.237	3.5
60	48	28.9	19.1	39.8	3.222	5.9	44.3	3.7	7.7	1.611	2.3
50	40	20.6	19.4	48.5	3.600	5.4	34.2	5.8	14.5	1.751	3.3
40	32	11.5	20.5	64.0	3.929	5.2	21.8	10.2	31.9	2.180	4.6
30	24	6.2	17.8	74.2	3.877	4.6	16.8	7.2	30.0	2.052	3.5
20	16	3.9	12.1	75.6	3.538	3.4	9.8	6.2	38.7	2.092	3.0
10	8	3.1	4.9	61.3	3.172	1.6	5.1	2.9	36.2	1.966	1.5
0	0	.....	.....	.....	1.978	.....	.....	.....	.....	1.429	.....

The green weight column is in its general tendency very similar to that observed in the nitrate table, namely, that the 32 parts per million cultures give the highest green weight whether dihydroxystearic acid was present or absent. The figures representing the average decreases and percentage decreases, on the other hand, correspond in trend more closely with those shown in the phosphate table, this similarity being especially shown in the last column giving the decrease per unit of green weight, in which a regularly descending column of figures is seen, although the latter column in the case of the dihydroxystearic acid is again somewhat uncertain in its general trend, as was the case in the nitrate table. In the case of the green weight the change from the 8 parts per million solutions to those containing no potash whatever was, as in the other cases, very marked and this was also distinctly noticeable in the solution where only potash was present. The results given in the three columns in the tables showing the decreases per unit of green weight

are consistent in showing that relatively more was absorbed when more was present, although the plant does not seem to have been able to utilize this increase economically in its growth. This tendency is especially marked in the case of phosphate and potash, although it is also shown to an appreciable extent in the case of nitrogen. The presence of the dihydroxystearic acid seems in nearly all cases to have interfered somewhat with this general trend, the least influence in this regard being noticeable in the phosphate table.

INFLUENCE OF DIFFERENT AMOUNTS OF P_2O_5, NH_3, AND K_2O, RESPECTIVELY, IN THE CULTURE SOLUTIONS OF EXPERIMENT II.

A comparison of the results obtained in Experiment II similar to that just described for Experiment I has been made so far as the analytical results were obtained. It will be remembered that only specific points, 26 in all, were determined. For a comparison by lines in this way these points are not as regularly distributed as might seem desirable, but the agreement with the general results obtained with the more complete number of cultures in Experiment I are indeed very striking and therefore support very well the results there given.

In Table XL are given the results for P_2O_5 in Experiment II computed and arranged in the manner described for Experiment I.

It will be noticed in this and succeeding tables that some of the lines are blank due to the fact that no culture solutions falling on the lines represented were analyzed.

TABLE XL.—*Showing the results obtained for P_2O_5 in the cultures containing different amounts of P_2O_5, Experiment II.*

Per cent of P_2O_5 in fertilizer mixture.	P_2O_5 content in original solutions.	Without dihydroxystearic acid.					With dihydroxystearic acid.				
		Average P_2O_5 in final solutions.	Average decrease of P_2O_5.	Percentage decrease of P_2O_5.	Average green weight.	Decrease of P_2O_5 per unit of green weight.	Average P_2O_5 in final solutions.	Average decrease of P_2O_5.	Percentage decrease of P_2O_5.	Average green weight.	Decrease of P_2O_5 per unit of green weight.
	P.p.m.	*P.p.m.*	*P.p.m.*		*Grams.*	*P.p.m.*	*P.p.m.*	*P.p.m.*		*Grams.*	*P.p.m.*
100	80	72.6	7.4	9.2	0.700	10.5	74.7	5.3	6.6	0.510	10.4
90	72										
80	64	48.8	15.2	23.7	2.090	7.2	53.0	11.0	17.2	1.150	9.6
70	56										
60	48	37.4	10.6	22.1	2.436	4.3	39.9	8.1	16.9	1.486	5.5
50	40	32.1	7.9	19.7	1.746	4.5	36.3	3.7	9.2	.875	4.4
40	32	23.2	8.8	27.5	2.486	3.5	27.8	4.2	13.1	1.293	3.2
30	24	16.1	7.9	32.9	3.063	2.6	18.4	5.6	23.3	1.700	3.3
20	16	10.9	5.1	31.9	2.647	1.9	12.4	3.6	22.5	1.952	1.8
10	8	3.7	4.3	53.8	2.704	1.6	5.6	2.4	30.0	2.038	1.2
0	0				1.616					.921	

It will be noticed, for instance, that the results with 40 parts per million are lower and do not appear to fall into the proper order with the other results of the column. This is true not only of this table,

but will be noticed in the remaining tables of this experiment and also in Experiment III, without a single exception. An examination of the diagram giving the number of cultures analyzed in this experiment shows that along this line having 50 per cent P_2O_5 there are three cultures, only one of which is in the middle, the other two lying upon the outside line and having only two constituents. The last two are always lower than the results in the middle, as has been brought out repeatedly. Above and below this line, however, are lines with three cultures likewise, but all are solutions having three fertilizers and give correspondingly higher results. This undoubtedly explains why this line with 40 parts per million shows throughout the experiment a lower average than the other line of cultures. Aside from this apparent inconsistency the table shows the same general result as that observed in Experiment I. In the column giving the average decrease it is noticed that the lowest result is found in the lowest concentration; it then increases in the higher concentrations and decreases somewhat in the very highest. The green weight also shows the same general trend, increasing with the decreasing phosphate content, except that the highest result in the cultures without dihydroxystearic acid is this time found in the 24 parts per million line. The highest individual result also lies in this line and is included in this result, being one of the cultures analyzed, thus making the average appear rather higher than it should. Moreover, the solution with the dihydroxystearic acid does not show this peculiarity. The last column giving the decrease per unit of green weight shows that this becomes less and less as the amount in the solution decreases. A comparison of the two columns with and without dihydroxystearic acid shows these to be much more nearly alike than was the case in the first experiment.

Table XLI gives the results obtained in Experiment II in the lines of cultures containing the same amounts of NH_3, grouped and arranged as in Experiment I, with the exception that the column for decrease per unit of green weight shows in this experiment a more regular decrease than was the case in Experiment I. A comparison of these two columns in the cultures with and without dihydroxystearic acid shows the figures in the latter case to be much the greater, a result which was already indicated by Experiment I.

TABLE XLI.—*Showing the results obtained for NH_3 in the cultures containing different amounts of NH_3, Experiment II.*

Per cent of NH_3 in fertilizer mixture.	NH_3 content in original solutions.	Without dihydroxystearic acid.					With dihydroxystearic acid.				
		Average NH_3 in final solutions.	Average decrease of NH_3.	Percentage decrease of NH_3.	Average green weight.	Decrease of NH_3 per unit of green weight.	Average NH_3 in final solutions.	Average decrease of NH_3.	Percentage decrease of NH_3.	Average green weight.	Decrease of NH_3 per unit of green weight.
	P. p. m.	*P. p. m.*	*P. p. m.*		*Grams.*	*P. p. m.*	*P. p. m.*	*P. p. m.*		*Grams.*	*P. p.m.*
100	80	55.0	25.0	31.3	1.370	18.2	52.6	27.4	34.2	1.020	27.0
90	72										
80	64	39.0	25.0	39.1	2.400	10.4	30.9	33.1	51.7	1.650	20.1
70	56	45.5	10.5	18.8	2.100	5.0	26.1	29.9	53.4	1.230	24.3
60	48	31.1	16.9	35.2	3.060	5.5	18.3	29.7	61.9	1.840	16.1
50	40	26.4	13.6	34.0	2.238	6.1	17.1	22.9	57.2	1.104	20.7
40	32	16.2	15.8	49.4	3.440	4.6	8.2	23.8	74.4	2.470	9.6
30	24	9.1	14.9	62.1	2.883	5.2	3.9	20.1	83.8	1.960	10.2
20	16	2.6	13.4	83.8	2.632	5.1	1.8	14.2	88.8	2.000	7.1
10	8	0.6	7.4	92.5	2.237	3.3	.2	7.8	97.5	1.322	5.8
0	0				.921					.432	

The results for the potash in Experiment II arranged along lines of different potash content are given in Table XLII, arranged and computed as before:

TABLE XLII.—*Showing the results obtained for K_2O in the cultures containing different amounts of K_2O, Experiment II.*

Per cent of K_2O in fertilizer mixture.	K_2O content in original solutions.	Without dihydroxystearic acid.					With dihydroxystearic acid.				
		Average K_2O in final solutions.	Average decrease of K_2O.	Percentage decrease of K_2O.	Average green weight.	Decrease of K_2O per unit of green weight.	Average K_2O in final solutions.	Average decrease of K_2O.	Percentage decrease of K_2O.	Average green weight.	Decrease of K_2O per unit of green weight.
	P. p. m.	*P. p. m.*	*P. p. m.*		*Grams.*	*P. m. p.*	*P. p. m.*	*P. p. m.*		*Grams.*	*P. p. m.*
100	80	46.7	33.3	41.6	1.033	32.0	55.7	24.3	30.4	0.415	58.5
90	72										
80	64	35.9	28.1	43.9	2.200	12.8	42.8	21.2	33.1	1.230	17.2
70	56										
60	48	24.0	24.0	50.0	2.655	9.0	27.2	20.8	41.3	3.000	6.9
50	40	15.9	24.1	60.2	2.202	10.9	26.4	13.6	34.0	1.298	10.5
40	32	10.9	21.1	66.0	2.990	7.1	14.7	17.3	54.1	2.105	8.2
30	24	5.2	18.8	78.3	2.886	6.5	10.9	13.1	54.6	1.790	7.3
20	16	5.6	10.4	65.0	2.956	3.5	8.2	7.8	48.8	1.313	6.0
10	8	3.8	4.2	52.5	2.220	1.9	4.6	3.4	42.5	1.254	2.7
0	0				1.073					.760	

The general trend of these results is the same as in Experiment I, and therefore needs no futher discussion here. The column giving the decrease per unit of green weight with and without dihydroxystearic acid shows in this experiment on the whole an increase in the case of the dihydroxystearic acid.

INFLUENCE OF DIFFERENT AMOUNTS OF P_2O_5, NH_3, AND K_2O, RESPECTIVELY, IN THE CULTURE SOLUTIONS OF EXPERIMENT III.

In Tables XLIII, XLIV, and XLV are given the results obtained in Experiment III for the influence of the various amounts of phosphate, nitrogen, and potash, respectively, computed and arranged in the same manner as in case of the two preceding experiments.

TABLE XLIII.—*Showing the results obtained for P_2O_5 in the cultures containing different amounts of P_2O_5, Experiment III.*

Per cent of P_2O_5 in fertilizer mixture.	P_2O_5 content in original solutions.	Without dihydroxystearic acid.					With dihydroxystearic acid.				
		Average P_2O_5 in final solutions.	Average decrease of P_2O_5.	Percentage decrease of P_2O_5.	Average green weight.	Decrease of P_2O_5 per unit of green weight.	Average in final solutions.	Average decrease of P_2O_5.	Percentage decrease of P_2O_5.	Average green weight.	Decrease of P_2O_5 per unit of green weight.
	P. p. m.	*P. p. m.*	*P. p. m.*		*Grams.*	*P. p. m.*	*P. p. m.*	*P. p. m.*		*Grams.*	*P. p. m.*
100	80	70.4	9.6	12.0	0.784	12.2	75.6	4.4	5.5	0.805	5.5
90	72										
80	64	52.9	11.1	17.2	1.909	5.3	54.0	10.0	15.6	1.320	7.6
70	56										
60	48	41.4	6.6	13.8	2.086	3.2	42.3	5.7	11.8	1.506	3.8
50	40	35.3	4.7	11.8	1.877	2.5	38.2	1.8	4.5	1.098	1.6
40	32	24.5	7.5	23.4	2.548	2.9	28.4	3.6	11.3	1.443	2.5
30	24	18.3	5.7	23.7	2.517	2.3	20.5	3.5	14.6	1.487	2.3
20	16	11.6	4.4	27.5	2.576	1.7	13.9	2.1	13.1	1.693	1.2
10	8	4.2	3.8	47.5	2.395	1.6	7.0	1.0	12.5	1.552	.6
0	0				1.915					1.201	

TABLE XLIV.—*Showing the results obtained for NH_3 in the cultures containing different amounts of NH_3, Experiment III.*

Per cent of NH_3 in fertilizer mixture.	NH_3 content in original solutions.	Without dihydroxystearic acid.					With dihydroxystearic acid.				
		Average NH_3 in final solutions.	Average decrease of NH_3.	Percentage decrease of NH_3.	Average green weight.	Decrease of NH_3 per unit of green weight.	Average in final solutions.	Average decrease of NH_3.	Percentage decrease of NH_3.	Average green weight.	Decrease of NH_3 per unit of green weight.
	P. p. m.	*P. p. m.*	*P. p. m.*		*Grams.*	*P. p. m.*	*P. p. m.*	*P. p. m.*		*Grams.*	*P. p. m.*
100	80	58.5	21.5	26.8	1.757	12.3	56.8	23.2	28.9	1.326	17.5
90	72										
80	64	39.4	24.6	38.2	2.201	11.2	43.2	20.8	35.2	1.360	15.3
70	56	40.2	15.8	28.2	1.970	8.0	27.7	28.3	50.5	1.518	18.7
60	48	28.9	19.1	39.8	2.485	7.7	24.4	23.6	49.2	1.615	14.6
50	40	20.5	19.5	48.8	2.309	8.4	19.6	20.4	51.0	1.586	12.9
40	32	14.6	17.4	54.3	2.749	6.3	11.8	20.2	63.1	1.553	13.0
30	24	10.3	13.7	57.0	2.294	6.0	6.9	17.1	71.1	1.601	10.7
20	16	1.2	14.8	87.5	2.642	5.6	2.6	13.4	83.7	1.490	9.0
10	8	.2	7.8	97.5	2.119	3.7	.6	7.4	87.1	1.291	5.7
0	0				1.115					.798	

TABLE XLV.—*Showing the results obtained for K_2O in the cultures containing different amounts of K_2O, Experiment III.*

Per cent of K_2O in fertilizer mixture.	K_2O content in original solutions.	Without dihydroxystearic acid.					With dihydroxystearic acid.				
		Average K_2O in final solutions.	Average decrease of K_2O.	Percentage decrease of K_2O.	Average green weight.	Decrease of K_2O per unit of green weight.	Average K_2O in final solutions.	Average decrease of K_2O.	Percentage decrease of K_2O.	Average green weight.	Decrease of K_2O per unit of green weight.
	P. p. m.	*P. p. m.*	*P. p. m.*		*Grams.*	*P. p. m.*	*P. p. m.*	*P. p. m.*		*Grams.*	*P. p. m.*
100	80	44.2	35.8	45	1.370	26.1	57.2	22.8	28	0.716	31.8
90	72										
80	64	24.8	39.2	61	2.100	18.7	41.6	22.4	35	1.128	19.9
70	56										
60	48	15.3	32.7	68	2.589	12.6	24.9	23.1	48	1.620	14.3
50	40	11.4	28.6	72	2.178	13.3	22.8	17.2	43	1.208	14.3
40	32	4.1	27.9	87	2.781	10.1	13.8	18.2	56	1.996	9.1
30	24	2.1	21.9	87	2.676	8.3	9.6	14.4	60	1.437	9.9
20	16	2.7	13.3	83	2.389	5.6	5.2	10.8	67	1.648	6.6
10	8	1.7	6.3	79	2.019	3.1	3.6	4.4	55	1.456	3.0
0	0				1.349					1.062	

Experiment III, it will be remembered, was conducted in the same manner as Experiment II, the same number of cultures being analyzed, differing only in that the experiment was shorter, being run for only four periods. In their general trend these results support in nearly every respect the points already brought out by the discussion of the preceding results.

The general results of the three experiments show very strongly that the highest average green weight is obtained in all cases on or below the 32 parts per million line. In the case of the phosphate it is usually below this line and in some of the experiments it is as low as the 8 parts per million line. The change occurring where one of the elements is entirely absent is always marked, as is also the case where only the element in question is present. The general result in the column giving the average decrease shows that this decrease becomes somewhat larger, though by no means proportionate with the increase in concentration of a constituent. It reaches practically a maximum in the 40 parts per million line, beyond which the decrease is somewhat constant and above which the higher green weight or plant development is never found. There is in general a dropping off in the very highest concentration.

In regard to the amount of decrease accompanying a unit of green weight, it might be said that the general result is that for every gram of green plant produced more decrease in the concentration of the solution was noticed the higher the concentration in that constituent. This would seem to show that the decrease in the solution was greatest in that constituent which was present in the largest amount. As was shown earlier in the paper, there is a tendency for the ratio in which the three plant foods are removed to approach a constant, as was shown in the diagrams where these ratios of the removed materials was given with the ratios of the materials left in the solution. It might be said, therefore, that this tendency to remove the same ratio was influenced by the constituent which was present in the greatest amount.

SUMMARY.

The foregoing investigations have given the following results:

(1) An organic soil constituent, dihydroxystearic acid, hinders the growth of wheat plants when this is present in solution in pure distilled water.

(2) The compound is also harmful in the presence of nutrient or fertilizer salts in all ratios of the fertilizer elements, P_2O_5, NH_3, and K_2O.

(3) The compound is more harmful in those ratios of fertilizer elements not well suited for plant growth.

(4) The harmful effect of the compound is the least in those ratios of fertilizer elements best suited for plant growth.

(5) The compound appears to be relatively much less harmful in the presence of fertilizers mainly nitrogenous than in the presence of fertilizers mainly phosphatic or potassic.

(6) The harmful compound modified greatly the removal of fertilizer elements from the solutions. The quantity of phosphate and potash removed was less in the presence of the compound, but the nitrate was not so influenced and on the whole the amount removed was even greater.

(7) The compound modified both amount and ratio of the three fertilizer elements removed from solutions, the ratio being higher in nitrogen, which was also the most efficient fertilizer element in decreasing the harmful effect, as above mentioned. Whether the action is on the compound direct or on the plant, enabling it to withstand the harmful effect or enabling it to reduce the quantity of the compound, is not determined.

(8) The harmful compound has the additional effect of darkening the root tips, stunting root development, causing enlarged root ends, which are often turned upward like fishhooks, and inhibiting strongly the oxidizing power of the roots.

(9) Those fertilizer combinations which tend to increase root oxidation are also the combinations which overcome the harmful effects to the greatest extent.

(10) Incidentally the investigations also throw much light upon the relations between plant growth and fertilizer action. In this study the growth relationships and concentration differences were observed between solution cultures in which the phosphate nitrate and potash varied from single constituents to mixtures of two and three in all possible ratios in 10 per cent stages. The better growth occurred when all these nutrient elements were present and was best in those mixtures which contained between 10 and 30 per cent phosphate; between 30 and 60 per cent nitrate; and between 30 and 60 per cent potash. The growth in the solutions containing all three constituents was much greater than in solutions containing two constituents, the solutions containing the single constituents giving the least growth. The concentration differences noticed in the solutions were also very striking, the greater reduction in concentration occurring where the greatest growth occurred. The change in the ratios of the solutions and the ratios of the materials that were removed from the solutions showed that where the greatest growth occurred, as above outlined, the solutions suffered the least change in ratio, although the greatest change in concentration occurred. The more the ratios in these solutions differed from the ratios in which the

greatest growth occurred, the more were the solutions altered in the course of the experiment, the tendency in all cases seeming to be for the plant to remove from any and all of these solutions the ratio which normally existed where greatest growth occurred, but was hindered in doing so by the unbalanced condition of the solution. The results show that the higher the amount of any one constituent present in the solution, the more does the culture growing in that solution take up of this constituent, although it does not seem able to use this additional amount economically. In the very early periods the ratio of phosphate absorption is low and the potash absorption high, although in final growth the greater response is obtained with nitrate, indicating relatively low phosphate requirement and high potash requirement of the seedling plant.

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